KANSAS STATE AGRICULTURAL
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ECONOMIC GEOLOGY

VOL. XVI. NOVEMBER, 1921. No. 7

ECONOMIC GEOLOGY OF THE OPHIR MINING DISTRICT.

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INTRODUCTION.

The Ophir Mining District is one of especial interest to the geologist, particularly at the present time, when it is becoming more and more evident that the discovery and development of future mines in the older mining regions must depend, to a great extent, on the intelligent application of the geologist's ideas to practical mining. The Ophir District lies on the western side of the Oquirrh Range, about sixty miles southwesterly from Salt Lake City by rail, and it is one of the early camps of the State of Utah. The Oquirrh Range and its continuation, the Tintic Mountains, including, as they do, the Bingham, Stockton, Ophir, Mercur and Tintic mining districts, is undoubtedly the greatest mining region in the State. As such it has had considerable attention from geologists, and, at least as regards the portions surrounding Bingham, Mercur and Tintic, has been the subject of very careful and detailed reports. The remainder of the range has not been nearly so well covered.

It has been the privilege of the writer to spend considerable time in the Ophir District during the past two years. So far as could be determined there have been but four reports on the district up to the present time, each of which is much generalized. They are as follows:

"Mineral Resources of the Territory of Utah," Ophir District, by J. R. Murphy, Salt Lake City, 1872.

"Mercur Mining District," by Spurr and Emmons, U. S. Geol. Surv. 16th Annual Report, Part 2.

"Ophir Mining District," by Keep and Ganse, *Mining World,* Volume 12, 1910.

"Ophir Mining District," by F. M. Wichman, *Engr. and Min. Jour.,* Volume 110, 1920.

The report by Murphy deals principally with the history and production of the camp prior to 1872 and hardly touches the geological conditions. That by Spurr and Emmons was made during their examination of the Mercur District and gives only a very general idea of the Ophir District, with the exception of the extreme southern part, which adjourns Mercur, and is described with more detail. The latest information and the most detailed to date is that furnished in Wichman's article in the *Engineering and Mining Journal.*

It was the writer's good fortune to be associated with Mr. Wichman in some of his work in Ophir. While precisely the same conclusions are not reached in all respects, hearty acknowledgment is due Mr. Wichman for his assistance and suggestions.

HISTORY OF THE CAMP.

According to Murphy, the earliest discovery was made in 1864. However, this was mainly base metals, carrying little silver, and but little interest was aroused at the time. Subsequently on August 23, 1870, W. T. Barbee made a discovery of high-grade hornsilver ore on the Silveropolis claim, on what is now known as Lion Hill. This discovery was very rich; assays are reported from $100 per ton to $20,000 per ton. Quite a rush ensued and by 1872, the date of Mr. Murphy's report, there were some fifteen hundred people in the district. Over eight hundred locations had been made and a steady output of high-grade ore developed. The first mill, the "Pioneer," of fifteen stamps, was built and put in operation in 1871. The estimated production in 1872 was about $290,000 gross.

Discoveries on the north side of Ophir Canyon and in Dry Canyon, still farther north, were made shortly after this. Active mining continued until the eighties, when the higher grade ore bodies were worked out. With the exception of two or three properties which are still producing, activities practically ceased at that time. The total output of the district is probably between thirty-five and fifty million dollars gross, of which fifty per cent. or more is attributed to the Ophir Hill Consolidated property, now owned and operated by Senator W. A. Clark. This property is apparently still far from exhaustion.

TOPOGRAPHY.

As previously noted, the Ophir District lies on the west side of the Oquirrh Range, southwesterly from Salt Lake City. It covers roughly the drainage area of two canyons, namely, Ophir or East Canyon to the south and Dry Canyon to the north. These canyons drain westerly into Rush Valley. In Ophir Canyon, which is the largest, and contains the present camp of that name, there is a small stream which flows the year through. The grade is not so steep as that of Dry Canyon, but has a number of steep pitches above which are wider alluvial flats which suggest glacial action. The sides of both canyons are extremely precipitous and rise to heights of two or three thousand feet above the canyons' floors. Both canyons head well up toward Lewiston Peak, which has an elevation of over ten thousand feet and is the highest in the range. The south side of Ophir Canyon opposite the town is locally known as Lion Hill. The north side is sometimes known as Ophir Hill or Treasure Hill.

PHYSIOGRAPHY AND GEOLOGIC HISTORY.

The State of Utah is divided into two geological provinces, known respectively as the Plateau Province, which embraces roughly the eastern half of the State, and the Basin Province, which covers the western half and extends on west through the greater part of Nevada. The Oquirrh Range is the most easterly of the Basin Ranges. It is some fifteen miles west from the foot

of the Wasatch Mountains, the boundary between the two provinces.

The oldest known formation in the Oquirrh Range is the Cambrian quartzite. In other parts of the State a large unconformity exists at the base of this formation, which would indicate a considerable period of erosion previous to the deposition of the Cambrian. Subsequently submergence took place which involved both the Basin and Plateau regions. At first the depression was probably very gradual and was partially compensated for by the deposition of sands in a comparatively shallow epicontinental sea.

Toward the beginning of the Middle Cambrian period the character of the sediments changed from sand to mud and silt, giving shales with occasional strata of impure limestone, and finally a large thickness of argillaceous limestones without definite shale strata. The continued acceleration of the sinking movement gradually brought about a cessation of the silt deposit and began the deposition of a thick series of magnesian limestones and dolomites. Deposition of this character continued through the remainder of the Middle and Upper Cambrian periods.

At the close of the Cambrian a general gradual uplift occurred, accompanied by the deposition of Ordovician, Silurian and Devonian sediments. These latter are present in the Tintic District, forty miles farther south, where they are topped by an unconformity. It is probable that in the Ophir District these sediments were meagerly developed and have since been removed by erosion.

After the Devonian a second period of depression occurred during which a thick series of Carboniferous rocks were deposited. These formations consist of limestones, sandstones and shales which are interbedded and repeated many times, testifying to the many and varied changes in the depth of the sea. The top of the Carboniferous is not exposed in the Oquirrh Range.

At the close of the Paleozoic Era or early in the Mesozoic a decided uplift again occurred which raised both the Basin and Plateau regions. It caused considerably greater emergence in the Basin than in the Plateau region, so that large areas of Mesozoic strata in the Plateau region were formed from the erosion of the Basin Province.

Following the Mesozoic a period of doming and thrust faulting occurred. This was either accompanied or immediately followed by a series of intrusive and extrusive eruptions, which initiated a general subsidence of the Basin Province relative to the Plateau Province and produced a partial reversal of the drainage. After the doming and thrust faulting, which produced generally north-south faults and folds, there occurred several great east-west uplifts, of which the Uinta-Bingham and Tintic-Deep Creek are prominent examples. It is probable that at this time the east-west normal faults were produced. These faults have been observed in many of the Basin Ranges and are generally down-throw to the south.

Subsequent to this, and probably due to the continued subsidence of the Basin territory, there occurred the latest series of normal faults, which strike roughly north and south and cut all other systems of faults, folds and uplifts. These faults are of large throw, generally being down-throw on the west side. They outline most of the Basin Ranges, as they are known today, on their west sides.

STRATIGRAPHY OF OPHIR.

Practically the whole of the Ophir District is covered by sedimentary formations, and it is in these rocks that the deposits occur. Therefore, consideration of them is essential to a proper understanding of the economic geology. In character they are quartzites, sandstones, limestones, dolomites and shales, ranging in age from Lower Cambrian to Upper Carboniferous, or Pennsylvanian.

In attempting to work out the stratigraphy of the district it was surprising to note that even in so small an area as this identical formations were known by different names in different parts of the district. Also, only those formations or strata which had some easily distinguishable lithological characteristics had local names. Mr. F. M. Wichman[1] suggested that, where applicable, the names of the various formations in the Tintic District as used by Lindgren could be applied to the Ophir formations,

[1] *Idem.*

and has so used them in his discussion. Although the correlation of sediments so far apart as this, principally by means of their lithological characteristics and order of occurrence, is seldom justifiable, in this case the evidence seems sufficient to warrant this classification.

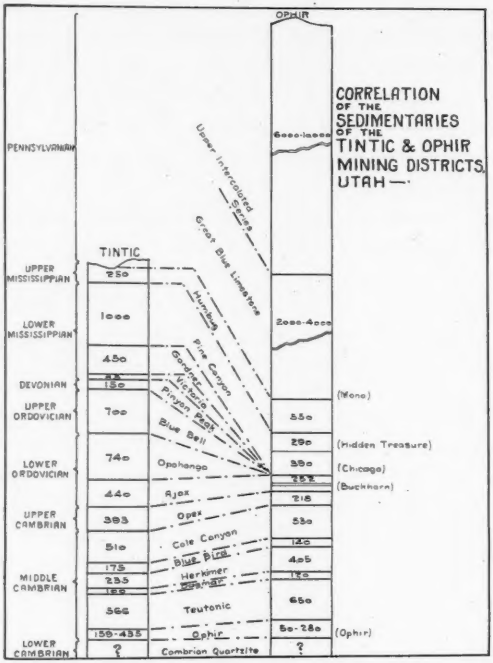

FIG. 29. Correlation of the sedimentary rocks of the Tintic and Ophir Mining Districts.

A tentative correlation of the formations of the Ophir and Tintic districts has been made (see Fig. 29). The left-hand column represents the formations noted by Lindgren and Loughlin.[2] The figures within the blocks represent the thicknesses in

[2] Lindgren, Waldemar, and Loughlin, G. H., U. S. Geol. Surv., Prof. Paper, 107, 1919.

feet and the notation at the right the names given to the various formations. The right-hand column represents the formations of the Ophir District as noted by the writer. The thicknesses are noted as in the Tintic column and the names current in the camp for several of the formations are noted to the right.

Cambrian Quartzite.—This formation, which is reported in other districts as varying from a thousand to six thousand feet in thickness, is the lowest exposed in the Ophir District, where only about three hundred feet of the top of the formation is known. The exposures occur in two adjoining gulches on the north side of the canyon above the town. The rock is grayish white to pale pink on fresh fracture, but weathers to a rusty brown. It has an even grain and, except near its contact with the overlying shale, is almost wholly pure quartz.

Ophir Formation.—Overlying and conformable with the quartzite is the Ophir Formation, which is a shale series containing a number of lenses of impure limestone. It shows a definite progression from the underlying quartzite, through siliceous shales, fine-grained compact shales with limestone lenses, to a banded argillaceous limestone similar to the overlying formation. The Ophir Formation is exposed on the north side of Ophir Canyon and Cambrian trilobites are reported from it. A large amount of exploration and successful mining has been done in this horizon.

There is undoubtedly a large variation in the thickness of the formation. It is believed that this can be explained in part by the presence of minor faults, which originated in the quartzite at the time of the doming movement and which die out in the overlying softer formations. Numerous strike faults of this nature are known in the Ophir Hill Consolidated workings. A very similar condition to this exists in the Tintic District at this horizon. In this case the faults were caused by the formation of a synclinal trough. Lindgren in his report on that district comments as follows: "The apparent variations (in thickness) are partly due to faulting. Most of the faults on the quartzite con-

tact not extending across the slates into the intercalated or overlying limestones."[3]

Teutonic Formation.—Above the Ophir Formation and conformable with it lies the Teutonic limestone. This member measures six hundred and fifty feet in thickness and in places appears even thicker, due to duplication of the strata by faulting. Neither the upper nor the lower boundaries are sharply defined because of the similar characteristics of the overlying and underlying formations. The rock is a banded, somewhat argillaceous limestone, very like the upper parts of the Ophir Formation, except that the banding is finer and more uniform. This formation is exposed over a large area on the north side of Ophir Canyon below the elevation of the buildings of the Cliff mine.

Dagmar Formation.—The Dagmar Formation overlies the Teutonic conformably. The lower boundary is not definitely marked. The upper boundary is sharply defined against the lowest member of the Herkimer. This formation is about one hundred and twenty feet thick. The rock varies from medium to dark gray on fresh fracture. It weathers for the most part white, but in places shows a distinct banding rather similar to the Teutonic. Toward the middle of the formation are several oölitic strata which serve as good horizon markers. On a weathered surface a peculiar light and dark mottling is an indicator of the oölitic texture. This formation is exposed only on the north side of the canyon, but diamond drill cores show its oölitic members in their proper position on the south side.

Herkimer Formation.—The Herkimer Formation is distinctly marked and clearly separated from both the underlying and overlying formations. Both contacts are conformable. It will be noted that this formation is considerably thicker here than at Tintic, and that it contains two shale members which are not known in that camp. The lower forty feet of this formation consists of a dark shale which weathers red. At about a hundred feet above this lower strata are several much thinner ones of similar character interbedded with the Herkimer proper. The

[3] *Idem*, page 25.

typical formation is rather similar to the Teutonic, the main difference being that the banding is not nearly as regular and continuous. It outcrops on the north side of the canyon near the Cliff mine houses. The total thickness is four hundred and five feet.

Blue Bird Formation.—This formation is the first of a thick series of dolomites and magnesian limestones. The minimum thickness noted, which is believed to best represent the formation, is a hundred and forty feet. The rock is a medium-grained, dark-colored dolomite, which weathers nearly black. Scattered through it are innumerable short white rods, suggestive of fossil remains. These markings are seldom over a quarter of an inch in length and are calcareous in composition. The formation is exposed on the north side of Ophir Canyon, above the Herkimer. On the south side it is only sparingly present, the majority of the formation being dropped from sight by one of the canyon faults.

Cole Canyon Formation.—This formation consists of a series of white and nearly black dolomites totaling five hundred and thirty feet in thickness. The dark beds are carbonaceous and some of them show markings rather similar to the Blue Bird Formation below. The light-colored beds are nearly white, medium-grained, completely crystalline dolomite, of high purity. The formation is exposed over large areas on both sides of Ophir Canyon.

Opex Formation.—The Opex Formation consists of alternating beds of light- and dark-colored dolomites. The darker beds are gray in color and show a peculiar and characteristic dark mottling, carbonaceous in character, surrounding fossil remains. No fossils have been found which were sufficiently preserved to be identified. Exposures are present over large areas on both sides of Ophir Canyon. The thickness is two hundred and eighteen feet.

Ajax Formation.—This formation consists of three members, totaling about two hundred and fifty-two feet in thickness. The lowest member (eighty feet thick) is a rather dark-colored dolomite, showing in places distinctive white eye-shaped markings

which suggest fossil remains. The middle member, locally known as the Buckhorn limestone, is about thirty feet thick. This member is not distinctive to the sight and shows much changed appearance in different exposures. Chemically it is the first bed above the Herkimer to be distinctly calcareous, rather than dolomitic, in composition. This member has produced considerable ore in the Ophir District and appears to be the first favorable horizon above the Ophir shales. The uppermost member of this formation is a rather thin-bedded limestone, lying in beds from two to eight inches thick and having decided argillaceous bands along the bedding planes, which weather readily to a whitish powder. This causes the formation to erode rapidly, so that outcrops are poor and in many places are readily overlooked. All three members of this formation are exposed on both sides of Ophir Canyon. They are also exposed in the bottom of Dry Canyon, about three quarters of a mile below the Hidden Treasure mine plant.

Unconformities.—In the Tintic District, Lindgren has noted[4] unconformities at the top of the Cambrian and at the top of the Ordovician. In speaking of the former, he describes the Ajax in Tintic as being laid upon a previous topography of mild relief with little or no angular divergence. The latter he describes as more prominently and distinctly developed.

In the Ophir District the evidence of these unconformities is lacking. Although the previous formation, noted as Ajax, has been rather arbitrarily placed in the Ordovician period, it is possible that these members are really the top of the Cambrian. There must have been a long period of quiescence when little or no deposition took place and with little or no disturbance until the deposition began of the overlying Pine Canyon Formation, which has been identified from fossils, by several observers, as being of Lower Mississippian age.

Pine Canyon Formation.—This formation consists of two members, totaling six hundred and eighty feet in thickness. The lower member (390 feet) is a rather dark gray, blocky limestone,

[4] *Loc. cit.*

showing some fossils. This member is characterized by bands of dark-colored chert spaced from one to several feet apart. These bands are nearly continuous and are from one to two inches thick. On a weathered surface they are very conspicuous, due to their hardness. The upper member of this formation (290 feet) is a rather pure limestone, showing many fossils and some nodules of chert. Locally it is known as the Hidden Treasure limestone and is the third known ore-bearing horizon of the district. The upper member is exposed on the south side of Ophir Canyon in a small patch near the anticlinal axis. There are large exposures of both members on the north side of the canyon and on both sides of Dry Canyon. The upper member is the lowest formation exposed in the Mercur District, to the south.

Humbug Formation.—This formation is a series of interstratified beds of sandy quartzite and more or less siliceous limestones totaling about five hundred and fifty feet in thickness. It is correlated with the formation of the same name in Tintic and represents what is known as the Lower Intercalated Series in the Mercur District.

The limestones of this formation vary from light gray to dark blue on fresh fracture. The darker-colored strata are the less siliceous. All weather to a light shade of bluish-white. The quartzite beds vary from a typical quartzite to a soft, almost unconsolidated sandstone. All are brown in color, both on fresh fracture and on weathered surfaces.

Ore has been produced from this formation in several widely separated parts of the district. It has been cut in the new Ophir Metal Tunnel, and it is interesting to note the similarity that exists between this section and the one given by Lindgren for Tintic. The two sections are as follows:

HUMBUG FORMATION AT TINTIC.

	Feet.
Brown quartzitic sandstone	12'
Black fossiliferous limestone	25
Brown sandstone	5
Blue limestone	4

Brown sandstone in part quartzitic	90
Bluish-gray limestone	3
Sandstone and limestone	50
Reddish sandstone	25
Gray sandy limestone	6
Sandstone	¾
Light brown sandy shale	30

HUMBUG FORMATION IN OPHIR METAL TUNNEL.

	Feet.
Brown sandstone	1
Black limestone	4
Brown quartzitic sandstone	12
Black limestone, fine to coarse-grained	38
Brown quartzite	30
Black limestone, fine-grained	3
Black limestone, fossiliferous	2
Brown quartzitic sandstone	5
Impure gray limestone	12
Brownish sandy limestone	23
Gray impure sandy limestone	20
Sandstone in part almost unconsolidated	25
Impure gray limestone	5+

This section does not represent the total thickness.

The Humbug is exposed over a large area on Lion Hill, from whence the outcrop pitches down along the strike and crosses Ophir Canyon above the Fiske property. From this point it runs diagonally up the north side and crosses the ridge into Dry Canyon, which it crosses above the Hidden Treasure mine, and thence runs along the north side of that canyon through the Brooklyn, Mono, Queen of the Hills and Dry Canyon Consolidated properties.

Great Blue Limestone Formation.—This formation overlies the Humbug conformably. It is not present in the Tintic District, but is very extensively exposed in Mercur, from which camp the name is adopted. In that district it is estimated to be as much as five thousand feet thick, but the upper limit is indefinite. As the formation is followed to the north through the Ophir District it rapidly thins out. Part of this disappearance is undoubtedly accounted for by the introduction of numerous

arenaceous strata such as are characteristic of the overlying Upper Intercalated Series.

The rock is a comparatively uniform massive limestone, of a dark gray-blue color, containing a little chert in nodules and numbers of minute fossils. It is free from magnesia and generally has a fresh appearance even on weathered surfaces. Two shale members are noted in this formation in Mercur. These are lime shales and in places are hardly distinguishable from the mass of the formation. They apparently do not persist continuously through the Ophir District, but similar strata are known in parts of the district. These are best developed on the north side of Dry Canyon. The bottom of this formation is exposed on Lion Hill, and it covers a large area in the head of both Ophir and Dry Canyons. In the latter case several producing properties have been located in this formation.

Upper Intercalated Series.—The Upper Intercalated Series, described in Mercur, is the highest formation exposed in the Ophir District. It is probably of Pennsylvanian age. The total thickness is not known, but it is certainly six thousand feet and possibly ten thousand feet. It consists of a series of rather thick beds of limestone, sandstone and quartzite, including many beds showing transitional phases between these three types. No ore of commercial grade has been reported from this formation to date. The formation is exposed in the head of both Ophir and Dry Canyons and forms the peaks in this vicinity.

IGNEOUS ROCKS.

Eruptive rocks are sparingly present in the Ophir District. Three types of intrusives have been noted. Two of these are known in the Mercur District, and are described by Spurr as belonging to the quartz porphyries. One is slightly more acidic than the other. They are called the "Eagle Hill Porphyry" and the "Birdseye Porphyry." The former is nearly white, fine-grained rock, showing occasional phenocrysts of quartz, feldspar and biotite. In the Ophir District it is exposed as a thin sill on Lion Hill. There is also a prominent dike of this type which

can be traced from the tailings ponds in Ophir Canyon up the north side to the ridge and on north across Dry Canyon to the limit of the district. There are also one or two other dikes of this type on the north side. The Birdseye porphyry is made up for the most part of large, well-defined phenocrysts of feldspar and biotite. Quartz is more sparingly present. This type is also exposed on Lion Hill.

The third type is not noted outside of the Ophir District. It is a greenish, fine-grained, crystalline porphyry of diorite or quartz-diorite composition. It is believed to be later than either of the others, although no place has been found where they are in contact. The only exposure noted is a small northeast dike about three feet in width that crosses Ophir Canyon just east of the schoolhouse.

While the actual area in the district which is covered by eruptives is small, and so far as is known they do not have much effect on the distribution of the ore bodies, it is believed that the parent mass from which these dikes were sent out exists at some unknown depth beneath the Ophir dome and is the source of the large mineral deposits that exist in the district.

STRUCTURE.

Structurally the rocks of the Ophir District form a large elongated dome, or a quaquaversal fold. The long axis of this dome runs about thirty degrees west of north and dips to the north at from ten to fifteen degrees to the horizontal, causing the dip of the formations to be steeper toward the north than the south. The center of this structure is approximately at the town of Ophir. Ophir Canyon cuts the dome nearly along its short axis in line with a series of normal faults which by shattering the formations has accelerated the processes of erosion. The formation of Dry Canyon, which is shorter and not so deeply eroded, was probably influenced by minor faulting and fissuring.

In attempting to visualize the relations of the various formations the shape and position of this dome and the influence of the major transverse faulting must be constantly born in mind.

FAULTING AND FISSURING.

The superficial evidences of faulting and fissuring are not pronounced, and it is only by familiarity with the stratigraphy of the camp that even the most important can be readily traced on the surface. The fissuring is apparently previous to the period of major faulting and occurred at the time of the doming of the strata. Fissures run in all directions, but with hardly an exception all of those which have produced ore bodies strike between N. 10° E. and N. 65° E. By far the greater number of these are limited much more narrowly to strikes ranging from N. 35° E. to N. 55° E. Fissures, both barren and productive, generally have a calcite gangue. An interesting exception to this is one fissure noted on the north side of Ophir Canyon, west of the Ophir Hill Consolidated mill, in which the gangue is almost wholly quartz. While no large ore body is known to be connected with this fissure, it carries galena and pyrite, with some silver. Where it is exposed it is in an unfavorable horizon for ore deposition and there has been no replacement of the wall rock. In the more soluble formations barren fissures have widened to large water courses in many cases. Many of these are open to the surface and contain fairly sizable caves. In a number of instances these fissures have obviated the necessity of mechanical ventilation underground.

Systems.—There are two systems of major faulting which are nearly contemporaneous and are for the most part later than the principal fissuring and mineralization. The first and most important of these systems is a series of normal faults, down-throw to the south, which strike about N. 65° or 70° E., parallel with Ophir Canyon and the minor axis of the dome. The first and largest of these faults runs along the north side of the canyon about nine hundred feet north of the bottom. It has a throw of about one thousand feet. Between this fault and the canyon bottom are two more having throws of seven hundred and two hundred feet respectively. The formations in the canyon indicate that there is one or possibly two more similar faults of smaller throw in the bottom which is covered with soil. About half way up Lion Hill on the south side is still another large

fault, known as Lion Hill Fault No. 1, which has a throw of between seven and nine hundred feet. Because of the curvature of the strata it is difficult to estimate the total vertical displacement. However, the general effect is to cause a relative depression of the formations on Lion Hill of from two thousand to twenty-five hundred feet in relation to the formations on Ophir Hill on the north side. A series of small normal faults, with throws of a few feet each, which dip to the north, are known in the Ophir Hill Consolidated mine. These faults are parallel in strike with the larger ones and are probably due to a settling back of the formations after the main faulting. The major faults have their greatest throw near the axis of the dome and rapidly die out in an easterly and westerly direction.

The second system is not nearly as uniform in direction as the first. These faults are nearly all normal and have strikes varying from N. 45° E. to N. 45° W. They are not known to cut the former system at any place and are apparently not displaced by them. In other words, the second system lies wholly within blocks determined by the first system. In Dry Canyon two faults of this system have been noted. One runs between the Queen of the Hills and Mono properties and one between the Mono and the Kearsarge properties. The result of these two taken with one fault of the first system, which cuts the lower Mono Tunnel, is to drop the block of ground between some seven or eight hundred feet. On the north side of Ophir Canyon is a fault of this system, known as the Cliff Fault. It is normal and has a throw of about two hundred feet, down on the east side. On the south side of Ophir Canyon are two faults of this system. The first is a reverse fault of about four hundred and fifty feet throw. The result is to divide Lion Hill into two segments south of Lion Hill Fault No. 1, with the easterly segment relatively upthrown. The second of these two faults runs along the bottom of Long Trail Gulch. This fault has not been finally measured, but the throw is several hundred feet upward on the east side. It is not known whether this is normal or reverse.

CHARACTER AND OCCURRENCE OF THE ORES.

Character.—The district has produced gold, silver, lead, copper, zinc and manganese ores of commercial grade. These metals generally occur as gold-silver-lead, gold-silver-copper, or silver-lead-zinc deposits. Only a very small amount of manganese has been mined, and in this case it occurred isolated from other deposits.

The gold-silver-lead and gold-silver-copper deposits are generally separate, but occasionally occur together as a combination of the four metals. Both sulphide and oxidized ores of this type are present. In the sulphide deposits the ore minerals are argentiferous galena, chalcopyrite, some chalcocite and occasionally a little sphalerite. The gangue minerals are calcite, barite, pyrite and a little quartz. These ores are almost entirely primary. It is certain that secondary sulphide enrichment has played little part in the formation of the ore deposits of the district. Oxidized ores of this type have undergone little migration. The ore minerals are cerargyrite, cerussite, malachite, azurite and cuprite. The gangue minerals are calcite, limonite, psilomilane, with some gypsum and quartz.

The silver-lead-zinc deposits are all rather completely oxidized. Ore minerals are cerargyrite, cerussite as sand carbonate, and smithsonite. The gangue minerals are generally the same as noted above. An almost complete separation of the lead and zinc minerals is usual, the zinc ore being found around the periphery of the lead ore bodies.

Favorable Formations.—Referring to the following table, showing the production from, and the location of, the various properties in the district, it will be seen that only a certain few of the formations known in the district have proved favorable to ore deposition. Taken in the ascending order of occurrence, they are as follows:

Ophir Formation.
Middle Ajax. (Locally known as Buckhorn.)
Lower Pine Canyon. (Locally known as Chicago.)

TABLE SHOWING GENERAL INFORMATION REGARDING SOME PROPERTIES IN THE OPHIR DISTRICT.[5]

Property.	Amount Extracted.	Location (L) and Formation (F).	Remarks.
Ophir Hill Cons....	$25,000,000.00[6]	L—Ophir Canyon. F—Ophir Shales.	Still producing. Pb, Cu, Ag and small Mn.
Fiske.....	500,000.00[6]	L—Ophir Canyon.	Fissure Deposit.
Hidden Treasure...	1,000,000.00[6]	L—Dry Canyon. F—Upper Pine Canyon.	Still producing, mined for Ag, Pb, Zn. Grade 15–40 oz. Ag. 20–50 per cent. Pb.
Ophir Metals Co. ..	None.	L—Lion Hill. F—Humbug and Upper Pine Canyon.	Prospecting below workings of old Lion Hill Cons. Mining Company.
Ophir Central Mines Co.....	None.	L—Ophir Canyon. F—Ophir Shales.	Preparing to prospect Ophir Shales south of Canyon faults.
Zella Group.....	750,000.00	L—Lion Hill. F—Humbug.	High Grade Ag-Pb ore.
Monarch Group ...	117,500.00	L—Lion Hill. F—Humbug.	Ore assays, Au .0.4 oz., 130 oz. Ag and 12 per cent. Pb.
Trace Group	12,000.00	L—Lion Hill. F—Humbug.	
Exchange and Sunnyside.....	80,000.00		
Lion.....	120,000.00	L—Lion Hill. F—Humbug.	High grade ore.
Chloride Point and Silveropolis.....	Many thousands.	L—Lion Hill. F—Humbug.	Production estimated from one to several millions.
Buffalo.....	.....	L—Lion Hill. F—Humbug.	Being worked by lessees.
Miner's Delight....	.....	L—Ophir Canyon. F—Ophir Shales.	Part of Ophir Hill Cons. Mining Co.
Ophir Coalition Co.	.....	L—Ophir Canyon. F—Ophir Shales.	Large tonnage low grade Ag–Pb ores.
Bonanza.....	.....	L—Ophir Canyon. F—Ophir Shales.	Much ore produced. Part of Ophir Hill Cons. Mining Co.
Cleveland Mining Co.....	100,000.00	L—Ophir Canyon. F—Ophir Shales.	$150 to $1,000 per ton.
Ophir Queen Mng. Co.....	None.	L—Ophir Canyon. F—Cole Canyon.	Prospecting dolomites south of canyon faults; no results.
San Joaquin.....	35,000.00	L—Ophir Canyon.	$100 to $400 per ton. Now part of the Fiske.

[5] Taken partially from notes on the district by Victor C. Hiekes. U. S. G. S. Prof. Paper No. 111; Ore deposits of Utah; and partially original.

Property.	Amount Extracted.	Location (L) and Formation (F).	Remarks.
Buckhorn	100,000.00[6]	L—Ophir Hill. F—Middle Ajax.	Produced several thousand tons of 20 oz. Ag and 36 per cent. Pb. ore.
Mountain Gem and Antelope	80,000.00[6]	L—Ophir Hill. F—Middle Ajax.	Produced several thousand tons of 20 oz. Ag and 30 per cent. Pb ore.
California	50,000.00[6]	L—Ophir Hill. F—Middle Ajax.	Ore, 25 oz. Ag and 55 per cent. Pb.
Chicago	500,000.00[6]	L—Dry Canyon. F—Lower Pine Canyon.	Ore in pipes at intersection of fissures.
Queen of the Hills	500,000.00[6]	L—Dry Canyon. F—H.G. Contact Upper Pine Canyon.	Has produced Ag, Pb, and Zn. Now under bond.
Dry Canyon Cons. M. Co.	35,000.00[6]	L—Dry Canyon. F—H.W. Contact Upper Pine Canyon.	Being operated under bond.
Mono	1,000,000.00	L—Dry Canyon. F—Great Blue Limestone.	Produced high grade silver ore.
Ophir Silver Mining Co.	None.	L—North branch Ophir Canyon. F—Upper Intercalated Series.	Prospecting highest formations of camp on supposed continuation of Ophir Hill Cob. fissures.
Kearsarge	$1,000,000.00	L—Dry Canyon. F—Humbug.	Long idle.
Deseret	30,000.00	L—Dry Canyon.	
Wandering Jew		L—Dry Canyon. F—Upper Pine Canyon.	Produced few hundred tons of 30 oz. Ag and 55 per cent. Pb ore.
Utah Queen	Unknown.	L—Dry Canyon. F—Humbug.	Large extraction reported.
Sacramento	Unknown.	L—Dry Canyon.	Large extraction reported.
Mountain Savage and IXL	60,000.00[6]	L—Dry Canyon.	40 oz. Ag and 25 per cent. Pb ore.
Emporia	30,000.00	L—Dry Canyon.	
Fourth of July	30,000.00[6]	L—Dry Canyon.	30 oz. Ag and 35 per cent. Pb ore.
Evening Star	Unknown.	L—Dry Canyon.	Some good ore reported.
Brooklyn	30,000.00	L—Dry Canyon.	

[6] Indicates estimated production.

Upper Pine Canyon. (Locally known as Hidden Treasure.)
Humbug. (Locally known as Lion Hill or Utah Queen.)
Great Blue Limestone. (Locally known as Mono.)

The ore bodies of the camp can be segregated into three types in reference to the factors controlling their deposition. The first and most usual is the type of replacement in favorable horizons along mineralizing fissures. The second is the type in which the ore occurs in pipes along the intersection of two fissures accompanied by some replacement of the wall rock. The third is the type in which the ore is deposited in the fissure itself with no replacement of the wall rock.

Replacement Deposits.—Deposits of the first group are responsible for the greatest tonnage. The ore deposits of the Ophir Hill Consolidated property are typical of this group. The ore occurs entirely in the Ophir Formation. Lenses of impure argillaceous limestone contained within the formation have been replaced along the lines of strong northeast fissures. Replacement has extended as much as forty feet either side of the fissures. The thickness of the ore varies between a streak and twenty-five feet and seems to be controlled to a great extent by the size of the replaced lenses. Very little replacement of the shale has been noted. The upper portion of the deposit is partially oxidized, but even before the present water level is reached the ore changes to sulphide form. Secondary sulphide enrichment could hardly have taken place in this case, because, due to the canyon faulting, no large portion of the deposit can have been leached or removed by erosion. The ore in this horizon has been ordinarily a fair grade of mill ore, with a certain proportion which could be sorted and shipped as crude ore.

In the higher horizons bodies of this type occur frequently, but as these upper productive horizons are all limestone, the ore is not confined to lenses as in the Ophir Formation. The bodies have generally been smaller in size, but much higher in grade, than the Ophir ore. Those of Lion Hill, and in fact of the

Humbug generally, have had a smaller lead content and a much increased proportion of silver. The gangue of the ores in this formation is highly siliceous, due to the solution and redeposition of silica from the numerous arenaceous strata present. The ore usually occurs in the limestone members of the formation. Ore bodies of this type in the Middle Ajax (Buckhorn) and the Upper Pine Canyon (Hidden Treasure) and the Great Blue Limestone (Mono) formations have generally had a fairly high lead content. All of the zinc ore of commercial grade has been mined from the Upper Pine Canyon formation in Dry Canyon. These ores have a much less siliceous gangue than those of the Humbug.

Pipes.—Deposits of the second type occurring as pipes at the intersection of fissures are confined to the oxidized lead-silver ores of the upper formations. Occurrences of this type are not uncommon in the Humbug, but the best examples known are in the Pine Canyon Formation, in the Chicago Mine and the Dry Canyon Consolidated property. With this type the ore is not always confined to the northeast fissures, but occasionally follows fissures in other directions. There is usually some replacement of the wall rock. Generally these deposits are small and seldom pay the cost of development and extraction. A notable exception, however, is the two large pipes mined in the Chicago, which are estimated to have produced in the neighborhood of a half a million dollars gross.

Veins.—The third type of deposit, in which the ore is entirely confined to the fissure, is rare. One or two instances are known in the Humbug on Lion Hill, but by far the most interesting case is that of the Fiske property. In this property the ore occurs in three large fissures which strike about N. 60° E. and stand nearly vertical. These fissures cut the unfavorable dolomite formations, which accounts in part for the fact that no replacement of the wall rock has occurred. Other unusual circumstances are that these fissures strike much more to the east than any others known to be productive, and that the deposit is much farther from the axis of the dome than any other in the district. The

fissures were mined to a total depth of eight or nine hundred feet and probably produced half a million dollars gross.

ORIGIN OF ORE DEPOSITS.

While the manner of occurrence and character of the ores is comparatively common, the origin of the solutions from which they have been deposited is much more obscure. Practically all of the ores of these types in the intermountain region can be connected more or less closely with eruptives, particularly with those of the intermediate type. The small amount of igneous rock exposed in the district, when considered in relation to the numerous ore deposits, precludes the idea of their being directly the source of the mineralization. A large intrusion is believed to exist beneath the Ophir dome, which is the parent mass from which the dikes have been sent out, and which is in part responsible for the dome itself. This intrusion is supposed to be at considerable depth, but probably within the Cambrian quartzite, which has been reported elsewhere as from one to six thousand feet in thickness. The mineralizing solutions rising through the unfavorable quartzite formation were probably fairly cool when they reached the favorable horizons above, where deposition took place. An interesting condition which supports this supposition and accounts for the absence of strong mineralization in the dolomites, through which the solutions must have passed, is the fact that the dolomites are much more readily soluble in hot than in cold solutions. In the Tintic District, where the dolomites were directly intruded, they are mineralized to a considerable extent.

At the time of the formation of the dome, when the fissuring is supposed to have taken place, the stresses developed transversely to the northeast fissuring must have been greater than in other directions, causing these fissures to penetrate to depths closely approaching the intrusion, and so providing channels for the mineral-bearing solutions, which could not reach the shallower fissures which strike in other directions.

PRESENT AND RECENT OPERATIONS IN THE CAMP.

At the present time work in the camp has been reduced to about the lowest possible point, due to the general depression in mining. The Ophir Hill Consolidated Mining Co. is operating their mine and mill on a one-shift basis with a small force. Mill concentrates are being stocked and no crude ore mined. Most of the underground work is development and it is reported that the results are satisfactory. The Hidden Treasure property is being operated on a leasing system with a small force. Regular shipments are being made as usual. The Buffalo property is being operated under lease. Leasers are operating on the Fiske, but no shipments have been made recently. In Dry Canyon development work is being done on the Dry Canyon Consolidated property and a small plant has been installed. Development work is also reported to be in progress on the property of the Ophir Silver Mining Co.

During the past year two interesting pieces of development work were started, which have been temporarily halted. The Ophir Metal Company began a cross-cut tunnel in Long Trail Gulch in order to prospect some of the lower formations under Lion Hill. This tunnel is now in about 1,450 feet and should be nearing the zone where the expectations of its projectors may be realized. The Ophir Central Mines Company has done diamond drill prospecting to locate the Ophir Formation to the south of the canyon faults, and to determine, if possible, the existence of ore bodies similar to those of the Ophir Hill Consolidated property. The result of this work was so encouraging that a shaft was started. An electrically driven compressed air and hoisting plant was installed. The company proposes to sink a two-compartment shaft ten to twelve hundred feet and prospect the Ophir shales south of the faults at this horizon.

CONCLUSIONS.

While a general geological report may be of interest to members of the profession, its real value, if any, lies in the aid it

may offer to the miner and prospector, who is often not a technical man.

It appears that in this district three factors are almost without exception present wherever ore bodies of commercial size and tenor have been discovered. These are:

1. The presence of one of the favorable formations previously noted.

2. Proximity to the long axis of the dome, where the deepest fracturing and greatest shattering has taken place.

3. Northeast fissuring. This system seems to have been the only one to serve as channels for the mineral-bearing solutions.

Generalities are dangerous and must be applied to particular cases with great caution. It must be borne in mind that the presence of all these factors does not of necessity mean the presence of ore bodies, but only that where these conditions hold, in this camp, the probability of discovering ore is enhanced. A considerable amount of work has been done in the district where these conditions did not apply, and with the one exception of the Fiske property no ore has been found.

OPHIR, UTAH.

GEOLOGY AND OIL RESOURCES OF COLOMBIA; THE COASTAL PLAIN.

ELFRED BECK.

INTRODUCTION.

The increasing demand for petroleum and its products has directed attention to the unexplored regions of South America. Because of its proximity to the United States, Colombia has been scrutinized and a number of development schemes have been put into operation during the last few years. Geological investigations have been made by nearly all the large oil companies and interest seems to be growing steadily.

The writer spent six months in Colombia exploring a large tract of land near the Caribbean coast. The work was carried on from March to August, 1919, for the purpose of making a geological map and report on the so-called San Andres concession.

This paper includes a detailed account of the geology in the vicinity of the concession, a reconnaissance report of the remaining area, and comparisons with the geology of Colombia as a whole.

This was a pioneer exploration, as no previous work had been done. Only a general outline map was available and little or no information has ever been published concerning the geology and geography of this territory.

Methods of Work.—The country is exceedingly difficult to investigate on account of the tropical climate and densely wooded regions. Horses and mules afford the only means of transportation. Although provision should always be made for "camping out," it is rarely necessary, for small towns are numerous and shelter under a palm-leaf roof can readily be secured. Hardships are many, and special care must be taken in the prevention of disease and sickness.

In swampy regions or in other impassable country distances to certain points were calculated by first determining the distance a crew of canoe-men could push a canoe in an hour, and then recording the distance traveled by the watch. The Brunton compass was used to determine the direction. The mule-pacing method was advantageous for general maps, where only approximate locations were called for. A plane table and telescopic alidade were used where accuracy was required and detailed results necessary.

Climate and People.—Geographically, Colombia is a tropical country, but it has great climatic diversity. The climate is tropical on the coast and low-lying river basins, but owing to the great relief and the curious configuration of the mountain chains, the climate becomes a matter of locality. At Santa Marta one can go from a hot climate to a cold one in a few hours. It is possible to reach an elevation of 18,000 feet on the Sierra Nevada Mountains. Regardless of the intense heat of the day, the evenings are always cool. In general there are two rainy seasons; the so-called winters from April to June and September to December; separated by two periods of dry weather. The average day temperature of the Magdalena and Sinu country is about 95 degrees and at night it may fall to 70 degrees.

The total area of Colombia is 461,000 square miles, and according to the census of 1912 the population was 5,500,000. The people are clustered together in small towns; rural districts are relatively few. The coastal inhabitants are a mixed race, probably of Spanish, Indian, and Negro blood. They are a law-abiding people with a great respect for foreigners.

GENERAL FEATURES.

Location.—The area discussed in this report lies on the Caribbean coast of Colombia, South America, and extends in a strip about 40 to 50 miles wide from the mouth of the Magdalena River southwest to Puertas Escondido. (See Fig. 30.)

Culture.—Roads in this part of Colombia are narrow and resemble cow-paths. The only improvements made on them con-

sist in cutting the brush twice a year. If this were not done, the road would be closed in less than a year's time. Occasionally a bridge is constructed. The main roads follow either divides or valleys and connecting lines are few.

It is interesting to note that town sites are invariably located on the outcrop of a sandstone formation or on the bank of a

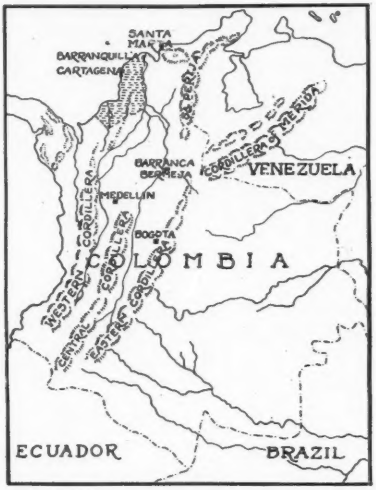

FIG. 30. Map of Colombia, South America, showing mountain ranges, drain-systems, area surveyed (shaded).

stream where there is a sandy soil. The larger towns, such as Cartagena, Barranquilla, Sincelejo, Monteria, Tolu, Carmen San O'nofre, Palmito, Lorica, and San Andres, have telegraph service, post offices, and some have electric-lighting plants. The first two mentioned cities are up to date in nearly all modern attainments and have a population of about 50,000.

Topography.—The region may be divided into lowlands, along the coast and river valleys, where dismal swamps, lakes and lagoons are numerous; and into an upland country, which is rugged and rocky. The altitude ranges from sea level to nearly

1,000 feet at several places on a divide, which trends northeasterly close to the center of the area. The ridges are comparatively uniform in height and are of prime importance in locating roads. The character of the underlying formations has influenced the shape of the hills, the more resistant rocks forming conspicuous outcrops or "Cerros" (from the Spanish, meaning hills), but the dip of beds is the determining feature. The outcropping ledges of sandstone and limestone incline at sharp angles, forming a series of escarpments which trend in a northeasterly direction. Some of the most prominent of these topographic features are: Cerro Tofeme, south of Chima; Cerro Bombo, near Huertas; Cerro Chiquito, north of Sabaneta; Cerro Pato, south of Sabaneta; Cerro Sapo, south of Toluviejo.

In this rugged territory erosion is active and deep gulches and valleys are characteristic. The region east of the Sincelejo anticline or east of the outcrop of the San Antonio sandstones is characterized by soft sandstones and shales dipping at low angles to the east, which produce a gentle rolling plain. The Palmito limestone forms a series of ridges or "Cerros" for a long distance across the area. This formation is inclined at an angle of about 90 degrees, and on account of its resistance to erosion the adjacent shale beds have been cut away, leaving the limestone in the form of an outlier. Caves formed by percolating surface waters are common in this limestone. The San Antonio sandstones cap the major part of the Sincelejo anticline and syncline and form the divide between the Magdalena and coastal drainage systems.

The tributaries of the Sinu and Magdalena rivers drain most of the area. The streams are intermittent and flow only in the wet season. The water ordinarily stands in pools along a dry bed or in artificial reservoirs, made by throwing dirt dams across creeks. Sometimes after heavy rains such streams as the arroyo Mucha, arroyo Pechelin, and arroyo San Antonio become dangerous raging torrents which are practically impassable.

The Sinu and Magdalena rivers are navigable for several hundred miles. A gasoline launch runs from Cartagena up the Sinu

as far as Monteria, making the trip twice a week. Accommodation for passengers is provided in addition to freight facilities. Transportation on the Magdalena is done entirely by large flat-bottom boats. Semi-weekly service is maintained between all points as far as Honda on the Upper Magdalena.

Underground Water Resources.—The topography of the country, the amount of vegetation, and the porosity of the surface are factors that control the amount of rainfall that enters the surface and gives rise to artesian and spring water. In this area the annual rainfall averages 90 inches and is unequally distributed throughout the year. The region is characterized by sandy soil and dense forest growth, consequently a large portion of the rainfall enters the ground.

The ground water table is constantly fluctuating; it rises in the wet season and sinks during the dry season. Several attempts have been made to secure fresh-water wells in the cattle regions near the Caribbean coast. Most of these have been failures. In all the cases examined by the writer it was found that the wells were dug in clays and shales, therefore yielding little or no water.

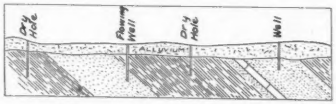

FIG. 31. Sketch showing the occurrence of water on coastal plain, near Madre de Dios.

If the wells were deepened, the chances of striking a porous or pervious limestone, a sandstone, or a gravel bed would be good. Fig. 31 illustrates why wells near Madre de Dios were failures, and shows a possible method for completing a good well.

At Sincelejo there occurs an ideal arrangement of the strata for obtaining an artesian well. Flowing water should be obtained at a depth of 150–200 feet, but deeper sands would develop a stronger flowing well, since the hydraulic head increases with depth. A detailed illustration is shown in Fig. 32.

An unusual occurrence of a fresh-water spring is found near Palmito, where the water penetrates a porous limestone (percolating down through bedding planes and crevices) and a sandy shale and produces the spring at the base of the hill.

FIG. 32. Sketch of the Sincelojo syncline, illustrating an ideal condition for an artesian well.

Good water wells may readily be obtained by drilling porous strata. If drilled beneath the lowest fluctuation of the water table the supply will be permanent, thereby relieving the scarcity which occurs every year, and at the same time improve the health conditions.

STRATIGRAPHY.

A rough sketch of the mountain ranges and drainage systems of Colombia is shown in Fig. 30. It will be noted that the mountain chains run in a northeasterly direction, producing lines of folding which range from north 15 degrees east to north 50 degrees east.

The mountain masses whose development have probably been the most active in determining the nature of the minor structural features in the coastal territory are the Western Cordillera Mountains to the south. The uplift which produced these mountains was so great that the foundation upon which the thousands of feet of Paleozoic and Mesozoic rocks were laid down is now exposed along the crest of this range.[1]

The stratigraphic column in the area shown on Fig. 33 is made up of rocks of early Miocene age. They are predominantly sandstones and shales, but some limestone is present. They have

[1] A generalized geological may of Colombia is given in U. S. Geol. Surv. Prof. Paper No. 71. The location and correlation of the formations are not absolutely correct, but the map will give some idea of the distribution of the rocks of different geological age.

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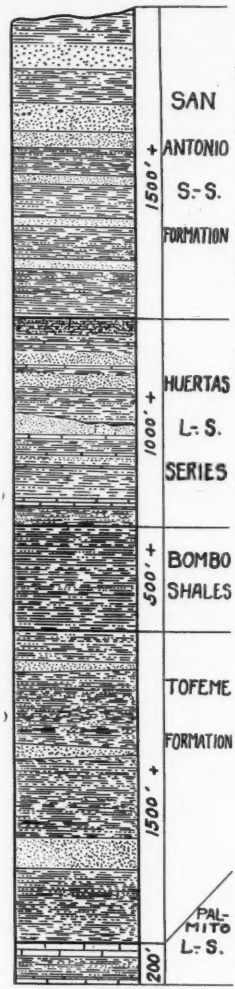

Light grey sandstone, locally conglomeritic.

Massive light grey to dark brown sandstone, forming rugged topography.

Thick sandstones. Light grey to dark brown. Alternating layers of shale and calcareous sandstone.

Thin limestone beds profusely fossiliferous. Many beds of soft friable sandstones.

A thinly bedded 30′ limestone. Contains few fossils.

A hard compact light grey shale. Color varies from blue to brown.

Red shales and light grey sandstones.

A massive sandstone 200–400′ thick.

Upper limestone bed is hard, snow-white, massive, without bedding planes. Forms conspicuous "Cerros." Lower limestone, friable thinly bedded.

FIG. 33. Generalized vertical section of the rocks exposed near Sincelejo, Department of Bolivar, Colombia, South America.

an aggregate thickness of more than 5,000 feet. It is believed that the position of these rocks in the Miocene series is not far above the horizon of the Eocene group. The exposed rocks are all sedimentary and names have been given to formations, according to the type locality in which they outcrop. This is the only attempt, to the writer's knowledge, that has been made to name the rocks in this region. Consequently the classification is subject to revision upon the selection of a better grouping.

Fossils are exceedingly scarce in the rocks in this vicinity. The Huertas Limestone Series contains the only known fossils. At San Andres three large sea-urchins were found and small marine brachiopods were numerous. From Buena Vista north, in the same formation, a large quantity of gastropods occur. The names of these fossils have not been ascertained. On the country roads about 35 miles from Barranquilla, near Usiacarii, a great number of well-preserved brachiopods were found. These are fancy corrugated shells probably of Pliocene age. At Tenerife, on the Magdalena river, just above Calamar, remains of a huge mammal have been collected. This specimen was identified by the American Museum of Natural History as the giant sloth *Megatherium,* but others have pronounced it a relative of the huge Mastodon which is found so abundantly in the Pleistocene of western Nebraska. The fossil is without doubt of Pleistocene age.

STRUCTURE.

Sincelejo Anticline.—The dominant structural feature in this territory is the Sincelejo anticline and it is best developed near the town of Sincelejo. (Fig. 34.) It is a narrow elongated anticline that extends in a general northeasterly direction for more than fifty miles. Practically the entire length of the fold is capped by the San Antonio sandstones. On the eastern slope of the anticline the beds dip to the east 5 to 30 degrees, while those on the west side incline at an angle of 45 degrees. (See Fig. 35.) West from the axis of the anticline the dip gradually increases, until at a point about ten miles west it is nearly verti-

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cal. Because the San Antonio sandstones diverge both north and south from this point, it is thought the form of the beds is that of a dome. Although not definitely determined, this anti-

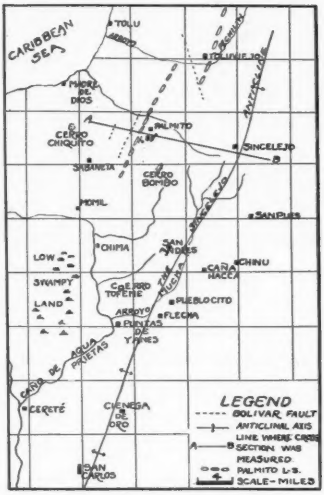

FIG. 34. Sketch map of the structural features in the vicinity of the San Andres Concession.

cline undoubtedly extends farther north in the direction of Carmen.

Sapo Fold.—The Sapo anticlinal fold or flexure occurs in the

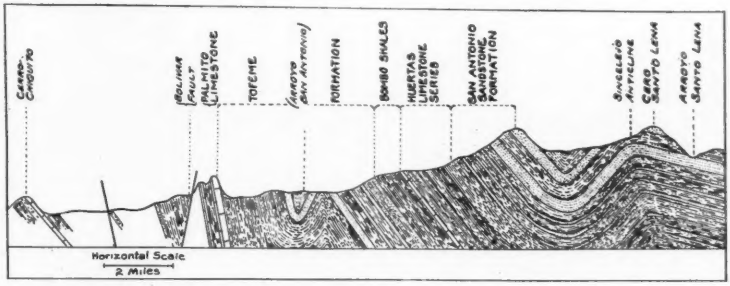

FIG. 35. Generalized horizontal cross-section measured along line A–B.

Tofeme formation. It outcrops in the road two miles east of Palmito, and can be traced north a few miles, where it appears to merge into a fault. The west limb of the structure dips sharply at angles varying from 60 to 75 degrees, while the eastern flank is inclined 35 to 50 degrees. Because of its narrowness and undetermined limits the fold is of no interest to the prospector.

San Andres Dome.—A well-defined dome is developed about two miles and a half southwest of the town of San Andres. It covers an area of one square mile. Outcrops of the Huertas Limestone Series completely surround the dome, and dips vary from 1 to 10 degrees. The beds are easily correlated and a detail structural map could be made.

Lorica Structure.—A few miles north of the town of Lorica the so-called "Lorica structure" extends in a northeasterly direction for a distance of about eight miles. The outcropping rocks probably belong to the Tofeme Formation. The anticlinal fold is symmetrical and the strata are inclined from 10 to 30 degrees. The north end of the elongated structure has the form of a plunging anticline, but evidence of a similar closure is not discernible on the south. The Standard Oil Company drilled a well on the eastern flank of this fold in 1915 to a depth of 300 feet. It is reported that a small showing of oil and gas was encountered.

Monteria Anticline.—An anticlinal fold has been interpreted to be present in the valley of the Sinu river, just north of the town of Monteria. This conclusion has been reached because the rocks dip to the west on the west side of the river, and to the east on the east side. Both sides of the hypothetical fold are upheld by outcrops of the same sandstones. Consequently some folding must have taken place. The anticline is paralleled on the west by a narrow syncline. Along the coast north of Puertas Escondido a prominent outcrop of calcareous sandstone outlines the syncline for a distance of ten miles.

Minor Folds.—There are several other folds or anticlines on the coastal plains of Colombia which the writer did not have an opportunity to visit. The combination of faulting and folding

which surrounds the Bolivar fault produces some complicated features. On account of these sharp inclinations very little work was done on this territory. However, with more detailed work, anticlines or geological structures of value to the oil prospector might be revealed. This would especially apply to the region east of Cartagena, where the dip of the beds is not so sharp, and where there are a large number of oil seeps. An anticlinal fold which occurs in the Pleistocene formation, a few miles southeast of Puerto Colombia, has been prospected for several years without any successful results. It is a long, narrow structure, covering about 10 square miles, and is similar to the one found at Lorica. Its outline is not well defined because the surface rocks are loose friable sandstones and shales, whose imperfect bedding planes yield unreliable dips and strikes. There are many other structural forms in Colombia of economic interest to the oil industry, particularly in the Santander district, where the Cretaceous rocks are exposed. These will be discussed further under the following heading.

PROSPECTING FOR OIL IN COLOMBIA.

Although petroleum has been known in Colombia for over a hundred years, no attempt has been made to develop this natural resource until recently, chiefly because the government was unfriendly toward foreign capital. This uncertain feeling has gradually changed, and now the oil industry is progressing successfully.

Drilling has been done at the following places:

(1) Puerto Colombia district, five miles southeast, near town of Turbara.
(2) The Turbaco district, 11½ miles southeast of Cartagena.
(3) Sinu district, near Lorica and Monteria.
(4) Baranca Bermeja district, 450 miles up the Magdalena river in the department of Santander.
(5) Pamplona district, near the Venezuelan boundary.

Puerto Colombia District.—The Puerto Colombia district has

undergone spasmodic development since 1907. Oil seepages and gas volcanoes are numerous, a fact that keeps operators incessantly at work. A Canadian company started operations by drilling 3 or 4 wells, ranging in depth from 600 to 3,000 feet. One of the wells yielded 7 to 8 barrels of oil daily and encountered several showings of gas. Later, in 1912 or 1913, the Kelly Oil Company commenced operations, and they are still at work in anticipation of finding oil in commercial quantities. Ten or more wells have been drilled with meager results. Information regarding the development of these wells is not given out, but it is certain that there is no startling production. Drilling has been done near oil seepages and on a small, narrow, poorly defined anticlinal fold. The softness of the Pleistocene formations has caused many difficulties. The churn drill was first used, but later, after several wells had to be abandoned on account of crooked holes, the rotary method was introduced. The company has a fully equipped up-to-date camp on their property, and they are hopeful of reward.

Turbaco District.—This district lies about 12 miles southeast of Cartagena. The writer has no information concerning the structural conditions in this vicinity. The surface evidence that has attracted attention is the large number of mud volcanoes. The Martinez Oil Company drilled the first well in 1908. In 1910 they combined with the Standard Oil Company of New York and drilled three more shallow wells, none of which were over 500 feet in depth. A new location was made in 1912 and a hole was drilled to a depth of 2,200 feet. Small quantities of oil and gas were encountered at various depths. Although these attempts were failures, they do not imply that oil does not exist in the underlying rocks. None of the wells were deep enough to be considered fair tests and the work was carried on with little geologic data. It is, therefore, improbable that these wells were drilled on favorable geological structure.

The Sinu District.—The Standard Oil Company, together with their Colombian associates, began exploration in the Sinu country in 1914. Two wells were drilled on the flanks of an anti-

clinal fold. The location seems to have been selected because of several oil seeps. Not only was the drilling done on an unfavorable structure, but the holes were sunk to a depth of only 500 feet. Therefore these wells can not be classed as fair tests. A year or two following the same company drilled a well near the town of Monteria, forty miles south of Lorica. Its depth has been reported at 2,000 feet. A small showing of oil and gas was encountered. This well was located near an oil seep and it is possible that it was placed on an anticlinal fold, but the interpretation of a hypothetical structure is still doubtful.

Baranca Bermeja District.—In the fall of 1915 prominent oil operators from Pittsburgh, Pennsylvania, visited Colombia and secured option on 2,000,000 acres of land near Baranca Bermeja. They organized the Tropical Oil Company, and operations were well under way in 1916. The first well was drilled near an oil seep at Infanta, 20 miles up the Colorado river from Baranca Bermeja. Fortunately, this location was made by a reliable geologist, and in the winter of 1918 the second well drilled came in with an estimated daily production of 5,000 barrels. The oil was found in Cretaceous rocks at a depth of about 1,500 to 2,000 feet on a well-defined anticline. Oil covered the Colorado river for miles before the well could be placed under control. The oil is light green in color and of a high grade, 42 to 45 degrees Beaumé. Its character may be seen from the following analysis:

ANALYSIS OF SEEPAGE OIL TAKEN FROM THE TROPICAL OIL COMPANY CONCESSION.[2]

Sample Number One.

	Per Cent.
Gasoline	1.00
Kerosene	41.00
Lubricating	53.00
Non-Volatile Residue	5.00
Sulphur	.55

This oil is either from the surface or else the origin of the oil is very

[2] From certificate of analysis No. 17648 by the Stillwell Laboratories, New York.

ancient as practically all the light benzine and naphtha has been driven out of it. It is a good grade of oil for the manufacture of kerosene and lubricating oils, and should also be well suited for the purpose of a fuel oil.

Sample Number Two.

Distillate from

Temperature Centigrade.	Volume Per Cent.	Specific Gravity.	Water.
150° to 240°	10.6	0.7996-46 Be.	0.2%
260° to 280°	15.5	0.8254-40½ Be.	
300° to up	8.2	0.8409-37 Be.	
Over 300° lubricating oil	46.5%	0.8441-36½ Be.	
Crackings	11.5	0.8441	
Residuum	7.7		

Sample Number Three.

Distillate up to 150° C.	1%	Water.
Distillate from 140 to 300 (Burning Oils)	22.5	
Distillate 300 up (Heavy lubricating oil)	60.	
Residue (Tar)	16.5	
Specific gravity of burning oils at 60° F.		0.8629
Specific gravity of burning oils at 60° F.		0.8961

No naphthas present.

Although petroleum has been discovered in commercial quantities, the problem of transportation has halted development temporarily. The Tropical Oil Company has been making attempts to sell their interests to some large company who would be able to finance the building of a pipe line to the coast. It is stated[3] that the Standard Oil Company has purchased the interests of the Tropical Oil Company for $40,000,000, most of which comprised an exchange of Tropical stock for International Petroleum Company stock. It is predicted that the new organization will begin extensive development and will also make arrangements to market the petroleum in Colombia and the United States in the near future.

Pamplona District.—According to Ralph Arnold,[4] oil both of high and low grade has been found at Pamplona near the

[3] *Oil and Gas Journal*, Feb. 6, 1920.

[4] "Conservation of the Oil and Gas Resources of the Americas," ECON. GEOL., vol. XI., p. 306, 1916.

Venezuelan frontier. The oil in this district occurs in Cretaceous limestones and sandstones and in the lower Tertiary. Long, well-defined anticlines in the Cretaceous rocks are the advantageous structures for accumulation. Faulted zones and overturned anticlines present other possibilities. The yield of the producing wells, which are all shallow, is small, but a larger production will probably be encountered at greater depth. The inaccessibility of this region is the cause for its slow development, even though the prospects at the surface are most encouraging.

Miscellaneous Districts.—At the present writing there are a number of companies operating or planning to operate in various parts of the country. The Carib Syndicate of New York has holdings in nearly every department in northern Colombia. They are now drilling at Honda on the Upper Magdalena. The Doherty interests have acquired one half interest in their Barco Concession, which property is now being developed. The Carib Company also has property in the Atrato river district, but this region is handicapped on account of its intolerable climate.

In the Department of Tolima, The Tolima Oil and Refining Company of New York are operating on the Montelier property, a tract of land comprising about 3,200 acres. The oil-bearing rocks are probably of Cretaceous or early Tertiary age and are a continuation of those in the Santander belt to the north. Oil seeps and petroliferous shales are found in abundance. There is an anticlinal fold on or near the property which might be an extension of the Tropical structure. A series of parallel faults characterizes this area for a distance of over thirty miles, and it is along these fault planes that seepages occur. These local disturbances and plications of the strata are factors that might hinder the accumulation of oil. However, the retention of oil in normal dipping beds, due to faulting, is a common occurrence, and this possibility might present itself in this particular region.

The Gulf Production Company, under the name of The South American Gulf Oil Company, has purchased the so-called San Andres Concession, a 200,000-acre tract, which lies in and around the town of San Andres. The only structure on the property is

a small circular dome, one square mile in extent. There are two oil seepages on the land, thought to occur along a fault plane about one mile east of the fold. A prospective oil sand, estimated at about 3,500 feet below the surface, and several other shallower possibly oil-bearing formations are the hopes of the operating company. They are now bringing in machinery and tools, building roads, establishing a camp, and making preparations for development of the Coastal Region of Colombia.

A group of promoters from Kentucky have secured a lease on 1,500,000 acres of land near Carmen, Department of Bolivar. There are a few oil seepages on the property. The writer is not definitely informed as to the structural conditions, but he believes that the Sincelejo anticline extends north across this area. This presumption has been upheld by statements received from other geologists who have visited the country. Under the name of the Caribbean Petroleum Company, this company either expects to do some drilling or to turn their holdings over to a larger company. This company also owns an option on a large tract of coal land in the Department of Antioquia.

The Emerald Oil Company of Winfield, Kansas, have acquired prospective oil and gas leases from The American-Colombian Corporation of Utah. The property lies up the Magdalena river near Magangue and comprises about 1,500,000 acres. There are many oil seepages on the property and it is the writer's belief that a large anticline, developed from the Central Cordillera Mountain Range, passes through the area a short distance west of the town of El Banco. The company expects to begin drilling immediately succeeding the close of geological and operation expeditions.

OIL-BEARING FORMATIONS.

The rocks in which oil has been found are of Upper and Lower Cretaceous and Lower Tertiary age. The oil has accumulated in sandstones in most all cases, but it has also been found in the porous limestones of the Cretaceous in the Department of Santander. The most promising oil-bearing formations are the sandstone members of the Tofeme Formation. This formation is

capped by the thick impervious Bombo Shales, which provides an ideal reservoir for the retention of oil and gas in water-saturated rocks. The Huertas Limestone Group also presents some possibilities, in which alternating layers of sandstones and porous limestones should be suitable horizons for oil and gas to accumulate.

OIL SEEPAGES AND MUD VOLCANOES.

In the foregoing review of the Colombian Petroleum fields only a few of the known oil seepages were mentioned. To attempt to enter into an exhaustive discussion of locations and descriptions of the numerous oil seeps would be beyond the scope of this paper. Therefore only the more important occurrences are given. The seepages occur in perfect uniformity, always paralleling some major uplift, which invariably trends in a northeast-southwest direction. This parallelism is the most striking characteristic of Colombian geology. It is observed in faults, anticlines, mountain ranges, oil seeps, and naturally in the drainage systems and topography. It acts as a guide many times in mapping and interpreting structural forms.

A prominent mud and gas volcano is located near Puertas Escondido on the Caribbean coast. It has five craters, and one cone is 15 feet high and 100 feet wide. A small amount of non-inflammable gas constantly issues from this "volcano." The force of the gas brings a grayish black mud to the surface, spreading and piling up the material in the form of a cone. This particular peculiar case is located on the flank and near the axis of a synclinal fold, contrary to the usual occurrences along fault planes and broken anticlines. In many of the oil seeps and mud volcanoes a long stick 15 to 20 feet in length can be thrust out of sight into the crater. These mud volcanoes in themselves should not induce operators to drill for economic supplies of oil or gas, as they are not proof nor an indication that petroleum is present in the vicinity. Unjustified locations near mud volcanoes have already met with failure.

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EDITORIAL

THE ZONAL DISTRIBUTION OF ORES AROUND IGNEOUS CENTERS.[1]

Several important mining districts in the Cordilleran region are marked by veins or other forms of deposits which furnish contrasted ores. Butte, Montana, is the one about which the most extensive and significant series of papers has been written. Many years ago the Butte Special Folio of the U. S. Geological Survey brought out in detail the interesting relationship, still earlier known to the mining fraternity, of a central east and west area of copper-silver veins, with pyrite and with characteristic quartz gangue, outside of which and circumferentially around which, on all sides except perhaps the east, were distinctively silver veins, with some galena, more zincblende, and with rhodonite and rhodochrosite as gangue. In the transitional region between the two areas a mine such as the Gagnon, even though based on the extension of the Anaconda fracture system itself, might show characteristics of both varieties of veins.

Increasing mining experience has somewhat diminished the sharpness of this areal arrangement. With the growing detailed knowledge, so well set forth in the papers of Reno Sales[2] and of Paul Billingsley and J. A. Grimes,[3] the impressive, successive systems of faults, of which three are ore-bearing, and the occur-

[1] Condensed from a paper presented at the first meeting of the Society of Economic Geologists, Chicago, Dec. 29, 1920.

[2] R. H. Sales, "Ore-deposits at Butte, Montana," Amer. Inst. Min. Engrs., Bull. 80, pp. 1523–1616, Aug., 1912.

[3] Paul Billingsley, "The Boulder Batholith of Montana," Amer. Inst. Min. Engrs., Bull. 97, pp. 31–47, Jan., 1915. *Transactions*, vol. 51, pp. 31–56.

Paul Billingsley and J. A. Grimes, "Ore-deposits of the Boulder Batholith of Montana," Amer. Inst. Min. Engrs., Bull. 124, pp. 641–717, April, 1917. *Trans.*, vol. 58, pp. 284–361.

rence of veins with manganese minerals within the territory of the older quartz-pyrite copper series, have become better understood. Veins, usually small, have manganese minerals even within the copper area.

By the increasing importance of the zinc production we have also learned that outside the distinctive copper-silver area very large deposits of zincblende may extend for two thousand feet or more in depth, in a fracture system belonging to the earliest east–west or quartz-pyrite series. Mr. Sales interpreted the relationships by the conception of a focal source of hot ore-bearing solutions which deposited copper in the central area. Around this central area, in an outer zone, remoter from the focal center, the zincblende, galena and manganese minerals were precipitated. In a slight further development the local Butte geologists now think of the concentric distribution around the focal center in three dimensions rather than in the two of a map; and imagine it as having an irregular ellipsoidal character. The conception seems to give a generalization which fits the known facts very well.

Billingsley and Grimes have emphasized in their studies of the great Boulder batholith and its various mining camps, considered as a whole, some further valuable results, which are extremely suggestive. They sought first to establish the original upper limit of the batholith with reference to its present surface, after restoring the eroded portion; and then to carry in mind the depth at which the present vein-walls stood when the vein filling took place. In some camps the older strata are still preserved which rested on the batholith at the time of its intrusion and are the wall-rocks of veins which continue downward into the lower-lying granite. When studied in this way, Billingsley and Grimes found for the smaller camps a widespread and characteristic, vertical distribution of the several ores, and plotted the results in many interesting sections. The highest vein-filling above the igneous source is gold-quartz. Below it are silver and silver-lead ores, becoming gradually richer in zinc in a range of a few levels. These ores pass gradually in an impressive number of

camps, into lean copper-bearing pyrite and quartz in the lower levels. In the smaller camps these relationships are very striking, but Butte is a center of such enormous vein development and of such unusual, expiring igneous action as to deserve special, individual study. The three successive fracture systems, the East–West, the Northwest and the Northeast, each with its mineralization, complicate matters; but all who are familiar with the large zinc mines will look with great interest to see if the relations in the smaller camps hold good for the large scale veins of Butte.

Recent, extremely detailed study of fifty or sixty miles of underground workings in the mines of Carr Fork in Bingham Canyon, Utah, have impressed on the writer some additional striking cases of zonal relationships; and with the view of suggesting study and interpretation of still additional camps along these lines the matter is here brought to wider attention. To all mining geologists of extensive experience other camps will come to mind wherein similar relationships may be cleared up.

In the mountainous ridge on the south side of Carr Fork is an intrusive monzonite mass, whose mineralization with original, lean, copper-bearing pyrites, followed by the familiar chalcocitic enrichment, has given rise to the huge operations of the Utah Copper Company. To the north of the surface outcrop of the monzonite mass and across Carr Fork is a series of over 2,000 feet of sediments, chiefly quartzites, but with four principal and some minor strata of limestone. The limestones were originally coal black in most instances, but contact metamorphism, produced by the intrusive mass and its offsetting dikes, has changed them for a distance, varying from a quarter to a half mile from the main mass, into lime-silicates and white marble. Nearest the intrusives, both along the large mass and the smaller dikes, we find epidote and garnet especially in evidence. Farther out, wollastonite and diopside predominate. Finally the white marble and lime-silicate rocks pass through spotted mixtures and interfingering transitions into black unaltered limestone. Nearest the igneous masses the great replacement bodies consist almost en-

tirely of copper ores with notable silver content. In the vastly preponderating proportion the minerals are pyrite and chalcopyrite, but tetrahedrite is also known and rarely, in vugs, appears in remarkably fine crystals. As we approach the border zone, where the contact effects begin to wane, the mineralogy of the ores changes. The copper compounds fail and galena and zincblende take their place, but the pyrite is persistent. This change may be observed in the same continuous ore-body. The lead and zinc ores may continue for hundreds of feet out in the black limestone, most significantly along lines of movement or crushes which follow the bedding. In only one or two relatively small instances was galena or zincblende observed by the writer near the intrusives, in the predominating copper-pyritic ores.

Now, when we come to interpret these phenomena we are quite irresistibly led to the conclusion that the earliest emissions from the igneous source brought the silica for the lime-silicates and such iron oxide or chloride as sufficed for the epidote and garnet and whatever subordinate specularite and magnetite may be present. The solutions with sulphides of iron, copper, lead, zinc and silver followed. Gold is very subordinate. The sulphides of copper and iron were precipitated from this chemical system together, at the higher temperatures and pressures prevailing near the intrusives. With them came down silver. The lead and zinc sulphides remained in solution to lower temperatures and pressures, and found their most favorable conditions for precipitation at the border of the lime-silicate zones and out in the black limestone. One almost vertical dip-fault was studied, beside which had developed above in the black limestone, as outward extensions along the bedding, large bodies of lead-silver ore. The same ores continued in the fracture, with limestone as one wall and quartzite as the other, until, after two or three levels, lime-silicate rocks took the place of the black limestone and copper ores began to be in evidence in the lowest drift. Pyrite is cosmopolitan in all these ore-bodies.

We would infer, furthermore, that as the igneous masses reached lower and lower temperatures, the physical conditions

near the intrusives were in the closing stages, similar to those which had prevailed at a distance in the earlier, maximum stages of ore-deposition. A little galena and zincblende were therefore precipitated near the source.

By reading of the literature on the artificial production of these minerals, and especially in the contributions from the Geophysical Laboratory in Washington, the writer has sought to get some light on the behavior of a complicated chemical system, involving sulphur, iron, copper, silver, lead and zinc. Undoubtedly from what we know of the formation of pyrite as against marcasite, and of zincblende as against wurtzite, the solutions were alkaline, so that the chemical system is rendered still more complex by the addition of alkalies. Undoubtedly it also existed at fairly high temperatures and pressures, and it encountered abundant calcium carbonate and calcium silicates. Beyond this general statement exact data seem to be not yet available. Possibly the complexity is beyond laboratory imitation. We may therefore be forced to interpret the phenomena largely in the light of pure reason.

The impression is quite widespread, although perhaps as yet somewhat vague and lacking sharp definition, that lead and zinc ores are often succeeded by copper ores in depth. Experience at Leadville, Colo., will come at once to mind, and there are, as earlier stated, other camps productive of several varieties of ores which will also suggest themselves. But the writer may perhaps be permitted in closing to express the hope that discussion may follow, in which not alone the vertical distribution will be considered, but also the lateral relationships with an intrusive mass, justifiably to be regarded as a source of heat, pressure and solutions.

JAMES F. KEMP.

DISCUSSION.

This department has been established by the editors in order to afford to those interested in questions relating to economic geology an opportunity for informal discussion. Contributions are cordially invited either in the form of discussion of more formal papers appearing in earlier numbers or bearing upon matters not previously treated. Letters should be directed to the Editor, Sheffield Scientific School of Yale University, New Haven, Conn. The full name of the author should be attached to all communications.

A CONVENIENT LOOSE-LEAF SYSTEM FOR FIELD MAPS AND NOTES.

Sir: Having benefited in numerous instances from the descriptions and discussions of practical field and office methods which have appeared from time to time in ECONOMIC GEOLOGY, and in the hope that others may find it useful, the writer is impelled to describe a system for field maps and notes which, after several years' use, he has found to have many advantages.

Some of the advantages of the system are: (1) It permits both maps and notes to be carried in the same container, a 5 x 8 inch clutch binder which fits readily into the pocket. (2) It preserves the maps from the wear and soiling to which field maps are usually subjected. A map at the end of a field season is in almost as good condition, physically, as at the beginning. (3) It permits ready cross-reference between map and notes without burdening the former with reference marks. (4) Both maps and notes may be assembled in permanent loose-leaf binders and classified and arranged in any way desired.

The equipment consists of (1) a 5 x 8 inch clutch binder, preferably hinged only on the front cover and opening along the 5-inch side; (2) one or more loose-leaf binders for 5 x 8 inch paper, punched along the 5-inch side; (3) a supply of loose-leaf coördinate paper. That which the writer is using is ruled into one sixth inch squares, but one tenth inch would, perhaps, serve just as well.

Below is a description of the method of using the system where one of the U. S. Geological Survey topographic sheets is being used as a base map:

The map is first cut into nine sections along the parallels and meridians. These sections fit readily into the note book. Each section is mounted on a sheet of ruled loose-leaf paper in such a way that the top and left-hand sides coincide with ruled lines on the paper. Glue or rubber cement may be used for mounting. The latter has the advantage that it does not cause buckling and is not affected by water.

The sections of the map are designated by an initial letter or abbreviation for the name of the sheet and a number for each of the nine sections, numbered from left to right from the top down. Thus the upper right-hand section of the Atoka sheet would be "A 3." The lower left-hand section would be "A 7." This designation is placed at the lower right-hand corner of the sheet.

On the side margins of the loose-leaf sheets, outside the map, the squares of the cross-section paper are numbered from the top down. Only every fifth number, 1.5.10, etc., is actually set down. This furnishes one of the coördinates for locating positions on the map. The other is furnished by a "cover sheet," which is simply a blank sheet of the coördinate paper, along the bottom of which the coördinate squares are lettered from left to right, beginning about as far from the left-hand margin as is the left-hand edge of the map.

In practice the sheet carrying the section of the map to be used is placed in the front of the binder with the cover sheet over it. The notes may be conveniently kept in the back of the binder, together with sections of the map not in immediate use. To make reference to a location on the map it is only necessary to slip the cover sheet up until its lower edge is on the point desired and is parallel to the lower edge of the map. Then, if the zero of the lettering of the cover sheet be placed at the left-hand margin of the map, the coördinates can be instantly determined. The location is recorded in the notes as "A 3, 10 j," "A 7, 26 p,"

etc. This gives the location to the nearest one sixth inch square without making any mark upon the map. If closer location is necessary, a dot on the map may be used. Even a small dot can readily be found at any time by reference to the coördinates of the imaginary square in which it occurs.

In the office the location of any point referred to in the notes can be instantly found, even on an uncut map, by lettering and numbering a card to correspond with the coördinates used in the field and using the parallels and meridians as guides for the various sections.

The method here described is applicable to other sizes of maps and loose-leaf note books, but there are important advantages in standardizing on one size. The 5 x 8 inch is probably the most convenient. Irregular sized maps can be cut into sections and used in the same way as the U. S. maps.

Inasmuch as paper is much cheaper than a geologist's time, it is a great advantage to use a separate sheet of paper for each note, even if it is only a few words. If this is done, a season's work can be classified, arranged, and rearranged in any way that is most convenient. When a report is being written all the notes on a particular location or topic can be quickly assembled even if the work of several seasons or of several men is involved. Full advantage of the loose-leaf principle is thereby gained.

JOHN L. RICH.

HOBART, N. Y.

LOGAN'S EXPLANATION OF THE ORIGIN OF INDIANA'S "KAOLIN."

Sir: In 1919 Mr. W. N. Logan, state geologist of Indiana, published a most interesting study of the halloysite deposits[1] of Indiana to which Cox in 1874 had applied the name "Indianite." In it he ascribes to anaërobic bacteria an essential rôle in the chain of reactions which resulted in the formation of the halloysite beds. His facts and conclusions may be summarized as follows:

[1] Logan, W. N., "Kaolin of Indiana," The Department of Conservation, State of Indiana, Publication No. 6, Indianapolis, 1919.

LOGAN'S FACTS AND INTERPRETATIONS.

1. All deposits of halloysite in southern Indiana are found at the contact of shales containing considerable amounts of FeS_2, with overlying beds of porous sandstone. The largest and best deposits are found where Pennsylvanian (Mansfield) sandstone rests along a strong erosional unconformity on Chester shales (containing beds of limestone and sandstone); here the deposits are localized along the bottoms of depressions on the erosion surface on top of the Chester Formation (pp. 25–27, 45–46).

This points clearly to ground water as an essential agent in the processes involved. The bottoms of these depressions would naturally have the best chances to be sufficiently saturated with ground water (p. 70).

At one locality (Gardner Mine, Lawrence Co.) the "Kaolin" merges at its base into a black clay, obviously of Pennsylvanian age (p. 24, p. 47, p. 53). Most of the following experiments were made with this black clay.

2. When the black clay from beneath the "Kaolin" is placed in water, a sulphate is extracted, which in its physical properties "seems . . . to correspond to some of the varieties of halotrichite, though it may be only a mixture of melanterite and alunogen. The accumulated sulphate may vary in composition with the abundance of melanterite and alunogen" (pp. 51–52).

These sulphates obviously result from the action of the oxygen of the ground water on the FeS_2 of the shale. The oxidation of the FeS_2 yields sulphuric acid and ferrous sulphate, known to the mineralogist as melanterite.

The action of the sulphuric acid on the clay produces the hydrated aluminium sulphate called alunogen in mineralogy (pp. 47–48).

3. When a sample of the clay is placed in water and allowed to settle, the water at first is clear and free from cloudiness of any kind. "Later the surface of the water becomes covered with a white film which becomes thick and finally forms a dense white web-like mass" (p. 57).

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The microscopic study, in which Mr. Logan was assisted by the bacteriologist, Professor E. O. Jordan, proved these web-like masses to consist of anaërobic bacteria, in form related to the sulphur bacteria of the genus Beggiatoa (p. 59). From this similarity it is assumed that the bacteria take sulphur from the ferrous sulphates (p. 73) and "store" it (p. 53).

4. The meshes of the interlacing bacterial fibers contain granular and spherical bodies of mineral matter. In cultures, after a period of time, these "granules dropped from the meshes of the filaments to the surface of the clay beneath the water" (pp. 62–66).

Professor R. E. Lyons analyzed the bacterial growths with their enmeshed mineral matter collected from the surface of a culture and desiccated. It was found to contain: SiO_2, 17.34%; AlO_3, 21.56%; Fe_2O_3, 3.38% (p. 66).

5. Under the microscope Indianite appears to be composed of "minute globular granules which are often arranged in a dendritic form" (p. 20). "The similarity of the microscopic grains found within the cells of the bacteria . . . to the grains in the . . . kaolin is remarkable" (p. 73). "Sometimes larger structures occur in the midst of the granules." They are typical spherulites with both concentric and radial structure. All transitional stages were observed in which the perfect original spherulite "disintegrates" into the granular ground mass, leaving finally at best a circular yellow stain. Similar spherulites are also found in the black clay below the Indianite deposits (pp. 20–21).

From (3), (4) and (5) the conclusion is drawn that the "kaolin is undoubtedly a secretion from the cells of the bacteria" (p. 63).

6. In the attempt to explain the processes involved in this remarkable "secretion" the following observations were used:

When black clay was placed in a vessel and covered with water, and no bacterial growths developed, evaporation caused a slight deposit of sulphate to form on the walls of the glass, above the water level. After a few days, however, deposition would cease

and the water surface would be covered with a film of iron oxide.

When black clay was placed in two vessels of similar dimensions, and a colony of bacteria was placed in one, the deposit of sulphate on the walls of the vessel with the thriving bacterial colonies was much greater than that of the vessel without bacteria. Since the film of iron oxide is expressedly referred to in the vessels without bacteria, and is not mentioned in the others, we are left to assume that in the presence of bacterial growths the film of iron oxide does not form (pp. 62–63).

From (6) the inference is drawn that the life reactions of the bacteria favor the formation of the sulphate. This action is supposed to consist in the removal of sulphur from the sulphates as follows.

Melanterite $FeSO_4$, $7H_2O$ consists of:

FeO	25.9%
SO_3	28.8%
H_2O	45.3%
	100.0

Alunogen $Al_2(SO_4)_3$, $18H_2O$ consists of:

Al_2O_3	15.3%
SO_3	36.0%
H_2O	48.7%
	100.0

"Both of these minerals are readily soluble in cold water, and it seems that they are absorbed by the sulphur bacteria, robbed of part of their sulphur and possibly secreted as a ferro-aluminium compound such as halotrichite," $FeSO_4$, $Al_2(SO_4)_3$, $24H_2O$, which consists of:

FeO	7.8%
Al_2O_3	11.0%
SO_2	34.5%
H_2O	46.7%

7. When the fringe of acicular crystals of sulphate which form on the walls of such bacterial cultures as described above

is scraped off and dissolved in water, it is found to give a greenish-white precipitate (*a*) with water glass, (*b*) with silicic acid in any form (silicic acid sol., fragments of quartz crystals, sand, etc.) (pp. 49–50).

From (7) the inference is drawn that this hypothetical halotrichite, formed as suggested under (5), would react with finely divided silicate, causing the "secretion" of "kaolin," or be carried by water until it comes in contact with sand or sandstone, where it could be changed into hydrous aluminum silicate (p. 49).

In the case of the Indianite deposits of southern Indiana, "in the presence of abundant water the sulphate passes upward into the bed of sand and, acting on the sand grains, replaces them with kaolin." Porosity of the kaolin would permit this process to continue, leading eventually to a far-reaching replacement of the sandstone by the kaolin. This would explain the occurrence of irregular sandstone blocks in "kaolin" (p. 70).

The replacement is thought to "extend downward" into the clay or shale "in presence of only a small amount of water"; but "upward," into the sandstone, "when there is an abundance of water present" to carry "the soluble ferro-aluminium sulphate upward" (p. 73).

SUGGESTED MODIFICATIONS.

Dr. Logan's experimental demonstration of the direct relation existing between the life processes of the observed bacteria and the production of "kaolin" is a most important contribution to our geochemical conceptions. It is unfortunate, however, that the conclusions which he has drawn from his experimental observations do not lead to any understanding of the processes involved. His views of the probable action of the bacteria may be summarized as follows:

(*a*) "They seem to secrete kaolin

(*b*) and their presence seems to be essential to the formation of large quantities of the ferro-aluminium sulphate which attacks the silica so readily.

(*c*) They may also assist in conserving the supply of sulphur which is so essential to continuous formation of aluminium sulphate." The supply of FeS_2 seems inadequate. "The sulphur which the bacteria take from the ferrous sulphates would ultimately be converted into sulphuric acid" (pp. 72–73).

The last paragraph contains the only definite allusion to the process that would entitle these bacteria to the name "sulphur bacteria." The name "sulphur bacteria" is commonly applied[2] to organisms that derive the energy necessary for their life reactions from the oxidation of hydrogen sulphide. (Incomplete oxidation results in the temporary separation of sulphur in the cell-protoplasm, hence the name.) Obviously Logan does not refer to this group of bacteria. The "ultimate conversion" of the sulphur into sulphuric acid is clearly thought to be a purely inorganic reaction.

Another group of bacteria, the sulphate-reducing bacteria, obtain the oxygen necessary for their life reaction from sulphates, ultimately reducing them to hydrogen sulphide. They are an important, if not the chief, source of this characteristic substance in sewage waters.[3] But they can not be said to "take the sulphur from the sulphates."

To the writer's knowledge the method of extracting sulphur which Logan ascribes to the bacteria observed by him is entirely hypothetical, as are also the supposed formation of the double salt halotrichite and the "secretion" of kaolin. The writer believes that it is not necessary to resort to such purely hypothetical processes in order to explain the part played by the bacteria in the formation of this kaolin. In its simplest terms the sequence of processes involved seems to be rather as follows:

[2] See, *e.g.*, Jordan, E. O., "A Text-book of General Bacteriology," 4th edit., 1914, pp. 97–99; or Marshall's "Microbiology," 2d edit., 1917, p. 358, and the paragraph on the Sulphur Cycle on p. 186.

[3] See, *e.g.*, the chapter on "Microbiology of Sewage," by E. B. Phelps in Marshall's "Microbiology," Philadelphia (2d edit.), 1917, pp. 279–281 (also p. 360). This action is entirely analogous to that of the denitrifying bacteria that derive their oxygen from the nitrates.

(*a*) The iron sulphide of the shale is oxidized, producing sulphuric acid and ferrous sulphate.

(*b*) The action of the free acid on the shale produces aluminium sulphate. (Leading upon longer exposure to the formation of "alum shales.")

(*c*) In addition to these soluble sulphates, colloidal silica is taken into "solution," as is evident from the fact that it reappears from solution in the next step.

(*d*) Then colonies of bacteria described by Logan are placed on such a solution, soon pellets of inorganic matter separate out in the meshes of the filamentous bacterial growths, consisting largely of alumina, silica and water, with some iron—that is, a substance essentially identical with the variable "kaolin" that forms the subject of the paper.

From this it appears that the action of the bacteria needs to be confined solely to reversing the process of solution, at least for the less soluble substances. The crux of the question we find, therefore, in the conditions of stability of solutions containing ferrous sulphate, aluminium sulphate, silica (also alkalies, etc.) and free sulphuric acid. A simple test shows us that a gelatinous precipitate forms when a solution of water glass is added to that of a mixture of ferrous sulphate and aluminium sulphate. When, however, a small excess of free sulphuric acid is added, the gel goes back into solution. The presence of *free sulphuric acid* is, therefore, *necessary* to *prevent* the formation of a precipitate. Its removal causes the separation of the silica from solution. Furthermore, it is known that salts of aluminium with the weak acids, such as sulphurous acid, can not exist in aqueous solutions. A reduction of the sulphate to sulphite would result, therefore, in the separation of aluminium hydroxide. Consequently, if some agency were to reduce the sulphuric acid and the sulphates, both the silica and the alumina would be forced out of solution. Since *sulphate-reducing bacteria are common in sewage, sapropels and soils, it seems highly probable that the bacteria observed by Logan belong to this group, and that their activity is directly responsible for the precipitation of alumina and the silica.*

While we must await the bacteriologist's confirmation of this suggestion, we may well give it our attention as a working hypothesis. According to it, the processes involved in the production of the halloysite beds of Indiana would have to be expressed as follows:[4]

(1) Oxidation of pyrite, furnishing ferrous sulphate and sulphuric acid.

$$FeS_2 + 7\,O \rightarrow FeSO_4 + H_2SO_4 + H_2O.$$

(2) Action of the free sulphuric acid on the shale substance, resulting in the formation of aluminium sulphate.

$$x.Al_2O_3.y.SiO_2.z.H_2O + 3x.H_2SO_4 \rightarrow x.Al_2(SO_4)_3 + y.SiO_2.aq.$$

(3) Ferrous sulphate, aluminium sulphate and colloidal silica held in solution by free sulphuric acid.

(4*a*) Reduction of sulphuric acid by bacterial action, finally leading to the formation of hydrogen sulphide.

$$H_2SO_4 + 8H \rightarrow H_2S + 4H_2O.$$

(5*a*) Separation of the silicic acid gel, resulting from removal of the free sulphuric acid.

(4*b*) Reduction of aluminium sulphate by bacterial action, forming the sulphite.

$$Al_2(SO_4)_3 + 6H \rightarrow Al_2(SO_3)_3 + 3\,H_2O.$$

(5*b*) Hydrolysis and separation of aluminium hydroxide, resulting from the formation of aluminium sulphite.

$$Al_2(SO_3)_3 + 3H_2O + aq. \rightarrow Al_2O_3.aq. + 3\,H_2SO_3.$$

(4*c*) Reduction of ferrous sulphate by bacterial action, finally leading to formation of ferrous sulphide.[5]

$$FeSO_4 + 8O \rightarrow FeS + 4H_2O.$$

[4] For the writing of the following formulæ the writer is greatly indebted to Dr. E. F. Farnau, of the Department of Chemistry of the University of Cincinnati.

[5] In the presence of free sulphur and hydrogen sulphide, the ferrous sulphide may be changed to the bisulphide: $FeS + S \rightarrow FeS_2$. A certain quan-

We may now turn back to the observational and experimental facts given by Logan and see to what extent they find their explanation by the processes outlined:

Ad 1. We realize at once the important rôle that is played by the porous sandstones overlying the halloysite of Indiana. The circulation of water within clay is so slow as to be negligible as far as securing a supply of oxygen is concerned. The ground water circulating in the porous sandstones, on the other hand, carries a sufficient supply of oxygen which will enter the shale by diffusion. The hydrogen sulphide, on the other hand, resulting as final product from the life of the bacteria, will escape from the immediate sphere of action of the bacterial colonies by diffusion also. Once beyond it, it will promptly be oxidized to sulphuric acid, which in time will produce more aluminium sulphate, being possibly a more active agent *in statu nascendi.* It is also quite possible that the production of hydrogen sulphide in the case of virulent bacterial growth may exceed its loss by diffusion, and may then have a toxic effect on the colonies. This would reduce bacterial action, if not stop it entirely. For a time oxygen would then restore the acids and sulphates, revive bacterial action, and so on in an endless cycle. Thus a small quantity of sulphuric acid would suffice to permeate and to transform whole deposits of shale. The only substances which would be returned to solution continuously in this process are sulphuric acid and ferrous sulphate. Both would therefore eventually suffer depletion through diffusion into the incessant current of ground water in the adjoining sandstone beds. This would explain the low percentage of iron in the resulting "kaolin."

Ad 2 and 3. These observations underlie this whole interpretation.

tity of finely divided sulphur may well be formed during the activity of the bacteria, while hydrogen sulphide and sulphuric acid exist side by side, according to the familiar reaction: $H_2SO_4 + H_2S \rightarrow SO_2 + 2H_2O + S$.

Concerning the formation of the bisulphide at ordinary temperature in the presence of finely dispersed sulphur and hydrogen sulphide, see W. Feld, "Über die Bildung von Eisenbisulphid (FeS_2) in Lösungen und die Entstehung der natürlichen Pyritlager," *Zeitschr. f. angew. Chem.,* vol. 24, 1911, p. 97.

Ad 4 and 5. The tendency to assume the form of minute or larger spherulites is entirely in harmony with the emulsoid colloidal nature of both aluminium hydroxide and silica.[6]

In the experiment (3) the meshes of bacterial growths held the growing spherulites in suspension as the masses of filamentous Schizophyceæ do on the shores of Great Salt Lake. The supposed action of sulphate-reducing bacteria is indeed strictly analogous to that of the denitrifying bacteria of the sea-water and of the filamentous algæ of Great Salt Lake.[7]

This process should, of course, not be called secretion. "Secretions" are defined by the physiologist as "substances subserving some purposeful end in the cell economy."[8] The kaolin in Logan's experiments, and calcium carbonate in Drew's, are by-products of bacterial life activity entering no way directly into its cycle.

Ad 6. If the bacteria in these shales are sulphate-reducing, the results of these experiments are readily understood. Without the bacterial growths at the surface of the solutions, the ferrous sulphate dissolved from the black shales was oxidized to ferric sulphate in contact with the atmosphere, which in turn was partly hydrolyzed into ferric hydroxide and sulphuric acid. The resulting film of hydroxide greatly reduced the rate of evaporation of the solution, and thereby also the rate of growth of the crystals along the edge of the solution.

The presence of colonies, on the other hand, prevented the oxidation of the ferrous sulphate, and thereby also the formation of a protective film. Evaporation proceeded consequently at a

[6] See Bucher, Walter H., "On Oölites and Spherulites," Journal of Geology, vol. 26, 1918, pp. 593–609.

[7] Compare Drew's account of the denitrifying bacteria of the Great Bahama Bank: "The elimination of the acid radicle from the nitrate in the process of denitrification, by whatever stages it may occur, must leave the alkaline base free to destroy the normal equilibrium of the salts in sea-water, and by increasing the alkalinity would result in the precipitation of calcium carbonate." (Drew, G. H., "On the Precipitation of Calcium Carbonate in the Sea by Marine Bacteria. . . ." Carnegie Institution of Washington, Publ. 182, p. 30.)

[8] Jordan, E. O., "A Text-book of General Bacteriology," 4th edit. W. B. Saunders Co., 1014, p. 92.

much greater rate, producing a much thicker growth of crystals along the walls of the vessels used.

SULPHATE SOLUTIONS AS SOLVENTS FOR QUARTZ.

Ad 7. The observation that quartz is attacked by ferrous sulphate and aluminium sulphate solutions is of great importance to the geologist and is the second contribution of fundamental importance made by Mr. Logan in this paper. The critical experiments are described by Mr. Logan as follows (p. 49):

"Experiment III. Halotrichite was dissolved in water in a glass beaker, in which broken fragments of quartz crystals were placed. The solution was allowed to stand for three days. At the end of that time a yellow stain was noticeable in the liquid and a slight precipitation occurred in the bottom of the beaker. The precipitate was filtered out and washed with dilute hydrochloric acid and water to remove the yellow iron stain. The test was then made for alumina and silica, and both were found to be present. The formation of kaolin was more rapid when bacteria were present.

"Experiment IV. Some very fine sand was placed in the bottom of a glass beaker, water was poured over the sand and some halotrichite was dissolved in the water. Bacteria were added after the solution had stood for a few days, a yellowish-white precipitate was noticeable on the surface of the sand. The precipitate gave reactions for alumina and silica. From time to time soil water was added and in the course of two months the sand had almost disappeared and kaolin had taken its place."

The geological importance of this observation becomes evident when we turn to the interpretation of the analyses of acid waters rich in silica, but low in alkali carbonates and high in strong acid radicals, such as, *e.g.*, that of the water of Youghiogheny River at McKeesport, Pa., quoted in Palmer's well-known paper[9] on the "Geochemical Interpretation of Water Analyses."

There are two reasons, however, why it seems improbable that this action played any important rôle in the formation of the

[9] U. S. Geological Survey Bulletin, 479, 1911, table 1, opp. p. 14.

"kaolin" deposits of Indiana. First, the primary clays contain all necessary silica that can readily enter into solution and be redeposited into the alumina. Since both the sulphuric acid and the alumina can be obtained only from progressively lower layers of shale, it would seem highly improbable that the solutions should secure their silica from the overlying sandstone rather than from the shale itself. Second, we have seen that a constant supply of fresh oxygen is needed to keep up the cycle of reactions. This can come only through a constant circulation of ground water in the overlying sandstone. Such a circulation seems indispensable, but would cause a dilution of the reacting solutions at the contact of shale and sandstone that would render the quantitative efficiency of the reactions at that point quite doubtful.

In conclusion, we can now give a more definite answer to the question, "Why are not such deposits of kaolin of more widespread distribution?" (p. 74). The factors which must combine to produce this effect are:

1. Original shales of such physical constitution as to readily yield sulphates when attacked by sulphuric acid ("alum shales").
2. Sufficient quantity of FeS_2 present in the shales.
3. The shales overlain by beds of sufficient porosity and adequate structure capable of conducting a constant stream of surface water charged with oxygen.
4. The accidental introduction of sulphate-reducing bacteria.

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THE ORIGIN OF GRAPHITE.

Sir: Ten years ago I wrote an article, which was published in ECONOMIC GEOLOGY, Volume 6, outlining a theory for the origin of graphite. This article has been cited repeatedly since then, and its conclusions have received favorable comment in many cases. However, one conclusion, expressed very briefly in that article, has met with criticism sufficient to call for some discussion of it. In the original article on page 221 may be found:

Graphite is practically insoluble in silicates at the ordinary temperatures of magmas; it is upon this fact that its value as a refractory material partly depends.

I believe as fully today as I did ten years ago that "graphite is practically insoluble in silicates at the ordinary temperatures of magmas." It must be admitted that the conclusion has not yet received experimental demonstration, and it seems unlikely on account of experimental difficulties that such a demonstration will be forthcoming in the near future. However, the experimental data so far obtained tend to show that graphite is insoluble in magmas. These data will be presented in later paragraphs.

It is important to state explicitly just what is meant by the statement that "graphite is practically insoluble in silicates." I recognized fully in the original article that carbon may go into solution in magmas in the form of some compound,[1] such as an oxide, and therefore it is clear that the original statement means that graphite *as such* is practically insoluble in silicates. That is, the type of solubility referred to is solution without chemical change of the substances concerned; or expressed in another way, it is solution in which the constituents concerned do not lose their identity through chemical change. Such solutions are illustrated by the mutual solubility of anorthite and diopside or enstatite and albite.

Bastin in an article on "The Graphite Deposits of Ceylon"[2] states that:

It has not been shown that carbon can not exist in igneous magma in the elemental form. The mere fact that graphite volatilizes only at

[1] This is shown in the following quotation from the original article (p. 228). "Any magma which contains sufficient water, upon coming in contact with bituminous or carbonaceous shales or slates, may be expected to convert all that portion of the carbon which is heated above about 600° C. to the oxide state through the agency of water. The resulting gaseous hydrogen and oxides of carbon, being soluble in water and silicate solutions under pressure, may be expected to move about with, and as freely as, the magmatic solutions themselves. Finally, when these solutions cool below about 600° C., graphite may be expected to crystallize out in much the same way as other minerals crystallize from the cooling magma."

[2] ECON. GEOL., vol. 7, 1912, pp. 419–443.

high temperatures under ordinary atmospheric conditions forms no valid argument against its existence in the elemental form in the rock magma at much lower temperatures. It would be as reasonable to say that since quartz is a highly refractory substance under ordinary conditions, it can not exist in magmas under much lower temperature conditions.

No discussion of this statement seemed necessary until Tilley in his article on "The Graphite Rocks in Sleaford Bay, South Australia,"[3] included the following paragraph:

For the extreme view of Winchell that graphite is insoluble in silicate magma there seems little justification. The argument based on the refractory nature of graphite does not necessarily hold for the conditions prevailing in igneous magmas nor sediments undergoing a strong metamorphism where the presence of volatile mineralizers is essential. As Bastin has remarked, it would be as reasonable to conclude that quartz was incapable of crystallizing out from melts at comparatively low temperatures.

An examination of my original article will show that I did not appeal to the fact that graphite volatilizes only at high temperatures under ordinary atmospheric conditions as proof that it is insoluble in silicate magmas. I made the original statement without citing evidences in proof of it, save the fact that graphite is used as a refractory material. This includes its use in the form of graphite crucibles in which silicates may be melted, as shown by the "slag tester" of Johnson.[4] The fusion of silicates in graphite containers would be impracticable, if not impossible, if graphite were soluble in silicates under atmospheric pressure at the temperatures concerned.

It is true that one of the recent textbooks[5] on ore deposits asserts that carbon is soluble to some extent in highly heated slags and in eruptive magma, from which it may crystallize either as

[3] ECON. GEOL., vol. 16, 1921, pp. 184–198.

[4] W. M. Johnson, *Trans. Am. Inst. Min. Eng.*, vol. XLIV, 1913, p. 139. Johnson devised a "slag-tester" composed wholly of Achesan graphite in which he determined the temperatures at which several score of slags would liquify.

[5] "Ore Deposits," Beyschlag, Vogt, and Krusch, translation by Truscott, vol. I, p. 129, 1914.

graphite or diamond under suitable conditions. However, the only evidence given in support of this statement is the fact that graphite and diamond have been found as constituents of igneous rocks, apparently separating from the magma at the time of its solidification. There is no evidence, therefore, that the carbon existed in the magma *as such* rather than in the condition of an oxide or other compound, since graphite formed by decomposition of a carbon compound in solution in the cooling magma would intercrystallize with the magmatic minerals.

Stutzer[6] states that graphite forms during the cooling of magmas, and that it has been produced artificially in a similar way; he makes no assertion that carbon is soluble as such in magmas, though that may be inferred from his account. Luzi[7] produced graphite artificially by mixing lamp black, potash (or soda) glass, calcium fluoride and water, and heating the mass to fusion. He states that fluoride and water seem to be essential, that the fusion did not go beyond a very viscous condition, and that the graphite was formed in the partly crystalline portion containing gas pores. These facts seem to me to make it quite probable that the graphite produced by Luzi came from the reaction by which CO is converted on cooling into carbon and CO_2, and that a reaction between lamp black and water was responsible for the formation of the carbon monoxide.

The experimental data which tend to show that carbon is insoluble in silicates relate specifically to the activity of this element as a reducing agent. By referring to various authorities on carbides and the thermo-chemistry of the reduction of metals it is possible to prepare the following table:

Of course, the preceding table does not show at what temperature carbon would reduce any silicate magma nor any silicate mineral, and the very meager information at hand indicates that some silicates are reduced at temperatures considerably higher than the temperatures of reduction of their constituent oxides.

[6] O. Stutzer, "Die wichtigsten Lagerstätten der 'Nicht-Erze,'" I., 1911, p. 79.

[7] W. Luzi, *Berichte deutschen chem. Gesel.*, 1891, p. 4085.

	At Least as Low as	At Least as High a.
Carbon reduces SiO_2 at temperatures	1460° C.[8]	2200° C.[9]
Carbon reduces Al_2O_3 at temperatures	1800° C.[10]	1940° C.[9]
Carbon reduces CaO at temperatures	1810° C.[9]	3000° C.[9]
Carbon reduces MgO at temperatures.....	1700° C.[11]	3000° C.[12]
Carbon reduces MnO at temperatures.....	1100° C.[13]	1750° C.[13]
Carbon reduces Fe_2O_3 at temperatures.....	425° C.[14]	1000° C.[15]
Carbon reduces $CaCO_3$ at temperatures.....	650° C.[16]	
Carbon reduces ZnO at temperatures	600° C.[17]	1188° C.[18]
Carbon reduces Fe_3O_4 to FeO at temperatures ...	528° C.[19]	
Carbon reduces H_2O at temperatures	500° C.[20]	
Carbon reduces FeO at temperatures	408° C.[19]	

Thus Johnson[21] notes that zinc silicate is reduced at temperatures much higher than those at which zinc oxide is reduced, and R. S. McCaffery[22] states that calcium aluminum silicate seems to be stable in contact with carbon in iron blast furnaces at temperatures which he believes to be considerably higher than the temperature at which carbon reduces lime. However, the less stable silicates, including hydrous silicates of iron, would probably be reduced at temperatures only slightly above those at which the oxides are reduced. Furthermore, acid magmas contain free silica and nearly all magmas contain small amounts of iron which, at least after solidification, are uncombined with silica. Finally,

[8] H. C. Greenwood, *Jour. Chem. Soc.*, vol. XCIII., 1909, p. 1483.

[9] O. Hönigschmidt, "Karbide und Silizide," 1914, p. 91, 70, 43, and 39.

[10] J. W. Richards, *Trans. Am. El. Chem. Soc.*, XXVII., 1915, p. 236.

[11] R. E. Slade, *Jour. Chem. Soc.*, XCIII., 1909, p. 327.

[12] O. L. Kowalke and D. S. Grenfell, *Trans. Am. Elec. Chem. Soc.*, XXVII., 1915, p. 221. At 2030° C. the reaction goes on *violently*.

[13] H. C. Greenwood, *Jour. Chem. Soc.*, XCIII., 1909, p. 1483.

[14] S. H. Stupakoff, *Bulletin of Engineering Society of Western Pennsylvania*, vol. 28, p. 499, 1912.

[15] Approximate upper limit of standard metallurgical practice.

[16] O. Boudouard, *Bull. Soc. Chim.*, XXV., 1901, p. 282.

[17] Lemarchands, *Revue de Metallurgie*, XVII., 1920, p. 840.

[18] W. M. Johnson, *Trans. Am. Inst. Min. Eng.*, vol. XLIV., 1913, p. 139.

[19] R. Schenck, *Phys. Chemie der Metalle*, 1909, p. 143.

[20] Weigert, *Abegg's Handb. Anorg. Chem.*, III., 2, 1909, p. 196.

[21] W. M. Johnson, *loc. cit.*

[22] Professor of Metallurgy in the University of Wisconsin, personal communication.

the state of combination of the water in magmas is an open question, and we may well believe that reduction of pressure would in some cases allow some of it to separate. Even if it remains in combination, or at least in solution, its reduction temperature is so low that it is probable that it would be reduced by carbon at ordinary magmatic temperatures.

No data have been found regarding the reduction of silicates by carbon, but it is known that iron silicates (chamosite, etc.) are used in France as iron ores, from which fact it may be inferred that they are reduced about as easily as iron oxides. Simmonds[23] found that a current of hydrogen removed part of the oxygen (that is, that part combined with the metal) from all types of lead silicates at red heat (in some cases before red heat), and also removed part of the oxygen from various natural silicates, including dioptase, chrysocolla, garnierite, connarite, chloropal, glauconite, cronstedtite, thuringite, stilpnomelane, and ilvaite. Fay and Seeker[25] found in certain experimental work that "carbon monoxide is a more rapid and efficient reducing agent than hydrogen." Carbon wholly unoxidized should be at least as strong an oxidizing agent as partly oxidized carbon in the form of carbon monoxide. That it has not been found to produce oxidation at temperatures as low as carbon monoxide is perhaps due to the greater activity of the latter on account of its gaseous form. But intimate mixtures of solid carbon and certain oxides have shown that the reduction by carbon begins at temperatures considerably lower than previously supposed, as shown, for example, by the work of Stupakoff, previously cited. In this connection the following data may be recorded:

CO reduces FeO at temperatures as low as 700° C. (and lower)[25]
CO reduces Fe_3O_4 at temperatures as low as 650° C.[25]
CO reduces FeO at temperatures as low as 540° C.[26]

[23] C. Simmonds, *Jour. Chem. Soc.*, vol. LXXXIII., 1903, p. 1449.
[24] I. W. Fay and A. F. Seeker, *Jour. Amer. Chem. Soc.*, vol. XXV., 1903, p. 641.
[25] A. Matsubara, *Trans. Am. Inst. Min. Eng.*, No. 1051, Feb., 1921, p. 11.

CO reduces Fe_3O_4 to FeO at temperatures as low as 350° C.[26]
CO reduces ZnO at temperatures as low as 350° C.[27]
CO reduces Fe_2O_3 at temperatures as low as 204° C.[28]
CO reduces roasted $FeCO_3$ at temperatures as low as 200° C.[29]
CO reduces FeO at temperatures as low as 200° C.[30]
CO reduces Fe_2O_3 at temperatures as low as 141° C.[29]

It may be assumed that any substance has a solubility in any other substance. We may then imagine that a minute amount of graphite becomes dissolved as such in a silicate magma. It would thereby become as efficient as a similar amount of gaseous CO dissolved in the same magma in producing reduction of oxide so far as its physical contact with those oxides is concerned, and inasmuch as it is not already partially oxidized, it would seem reasonable to believe that it would be at least as efficient as the carbon monoxide from a thermo-chemical point of view.

According to the graphs of Matsubara,[31] it appears that the reduction of Fe_3O_4 to FeO takes place at a lower temperature and at a considerably lower concentration of the reducing agent than the reduction of FeO to Fe; and, further, that the reduction of Fe_2O_3 to Fe_3O_4 takes place at a temperature even lower, and at a concentration of the reducing agent even less, than required for the reduction of Fe_3O_4 to FeO.

It may be worth while to take this opportunity to offer a few comments on the theory of T. H. Clark[32] that graphite has been derived from carbonates, at least in some cases. I agree entirely with Clark that carbonates are dissociated under certain conditions of contact metamorphism into carbon dioxide and metallic oxides, the latter forming silicates probably simultaneously. Clark says on page 183:

> Granting that the chemical processes upon which Dixon, Winchell and others base their formulas are correct, the geological materials required are water and carbon monoxide or carbon dioxide.

[26] E. Baur and A. Glässner, *Zeit. phys. Chem.*, XLIII., 1903, p. 361.
[27] Lemarchands, *op. cit.*
[28] Bell, *op. cit.*
[29] Stupakoff, *op. cit.*
[30] G. Charpy,, *Compt. Rend.*, CXXXVII., 1903, p. 120.
[31] A. Matsubara, *loc. cit.*, p. 7 and 8.
[32] Econ. Geol., vol. 16, 1921, pp. 167–183.

I believe that carbon monoxide in magmas is an adequate source of graphite, requiring the presence of no water nor carbon dioxide, and changing to carbon and carbon dioxide as a consequence merely of cooling. It is worthy of note that the change from carbon monoxide to carbon and carbon dioxide may occur at a temperature[33] as low as 320° C., provided the pressure *increases* to 600 atmospheres.

Water is of no known importance[34] in the production of graphite, except as a source (with carbon) of carbon monoxide.

The cooling of carbon dioxide does not produce graphite nor carbon without the intervention of some reducing agent. As suggested in my original article (p. 229), such an agent may be found in the hydrogen which is reported in some volcanic gases; furthermore, ferrous iron oxide is competent to act in this way with the production of ferric iron oxide, and this reaction may be responsible, not only for the production of some graphite, but also for the abundance near limestone contacts of ferric minerals, such as acmite and hematite. Carbon dioxide dissociates[35] to produce carbon monoxide and oxygen at temperatures above 1,300° C. under a pressure of one atmosphere. But the proportion of carbon monoxide produced is very small below 2,000° C., and would be reduced by increase of pressure. Finally, this reaction can hardly be responsible for the formation of graphite, because the latter forms during cooling at temperatures at which the magma crystallizes, and at these temperatures the carbon monoxide would be reoxidized to carbon dioxide, since the reaction is reversible.

Clark evidently was not aware that Spence[36] discussed favorably a year ago the idea that graphite may be produced by the dissociation of carbonates and the later reduction of carbon dioxide.

[33] E. Briner and A. Wroczynski, *Compt. Rend.*, 1910, vol. 150, p. 1324.

[34] Doubtless water is also important as a "mineralizer," keeping minerals in solution, reducing viscosity, and promoting coarse crystallization.

[35] L. Babu, "Traité de Metallurgie Générale," 1904, I., p. 218.

[36] H. S. Spence, "Graphite," Canada Dept. Mines Mem. 511, 1920, p. 9.

Parsons, as a result of experimental work, states[37] that "from new experiments, it is concluded that in the artificial production of diamonds in molten iron, the presence of gases, especially of carbon monoxide, is favorable."

Alling[38] has just published a brief discussion of the origin of graphite in which he states that the field facts in the Adirondack graphite district support the view that pegmatites transferred carbon from sediments to contact zones and true fissure veins. He says that this conclusion "is opposed to Winchell's view that graphite is insoluble in silicate magmas."

In my opinion there is no conflict whatever between the field facts cited by Alling and the view that graphite is insoluble in silicate magmas. Alling himself emphasizes the importance of water in the process of transfer, and it is my view that water and carbon produce carbon monoxide which is known to be readily soluble in magmas under pressure. As I have explained, the same compound may later yield graphite as a normal product of cooling.

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[37] C. A. Parsons, *Engineering*, Vol. 105, 1918, p. 485; abstracted in *The Amer. Mineralogist*, Vol. 4, p. 43.

[38] H. L. Alling, "The Origin of Graphite," ECON. GEOL., XVI., 1921, p. 334.

REVIEWS

Soil Alkali, Its Origin, Nature, and Treatment. By FRANKLIN S. HARRIS. 246 pp. In Wiley Agricultural Series. John Wiley and Sons, Inc., New York. $2.50.

As indicated by the title this work on soil alkali is rather comprehensive in scope, touching upon most of the phases of the alkali problem. It is however quite brief and is commendably free from subject matter not directly related to soil alkalinity. It is written clearly and in such simple terms as to appeal to interested laymen and students as well as to soil technologists. The book is obviously not intended to be an exhaustive treatise but it presents the salient facts in interesting fashion. An excellent series of references follows each chapter for the use of those who wish to pursue the topic discussed in the chapter somewhat further. Numerous illustrations are included but the cuts are not particularly well made.

From the standpoint of the geologist the discussion in this book is of interest because it indicates how efficient a transporting agent underground water is in some districts and how both relatively rapid degradation and aggradation may occur locally without the aid of surface running water, through the transfer of the soluble content of soils and rock terranes.

Bringing together the chief data on a problem of considerable importance in the utilization of our western lands, the book should prove popular for teacher, student, layman and engineer.

JOHN P. BUWALDA.

The Nomenclature of Petrology. By ARTHUR HOLMES. London, Thos. Murby & Co., N. Y., D. Van Nostrand Co. Pages 248. 8vo. Cloth. Price $3.50.

This book is a dictionary of modern terms that are likely to be met with in the literature of petrology. The author's hope is that the book may serve as a standard of reference which may to some extent limit future vacillation of terms and may be useful by serving as a guide to those who need to found petrological literature or to contribute to its pages. The volume contains definitions of all rock names, rock textures

and rock structures and terms used in describing and classifying rock masses. In many instances references are given to the papers in which the words are first defined or discussed, and in nearly all cases the name of the author proposing them and the date of his proposal are noted. The choice of the words comprising the glossary is excellent. All bizarre terms, odd prefixes and complex combinations that have from time to time been suggested for use but which have not been adopted are omitted; but otherwise practically every technical term that is employed by modern writers finds a place in the list. The definitions are brief but comprehensive and they appear to express well the meaning of the words they define.

Among the most valuable features of the boook are the appendices containing the translation of French and German terms, the meaning of Greek and Latin words that have been used as prefixes or roots in compounding petrographic terms or that have been imported bodily as the names of minerals or rocks, and a tabular classification of rocks and ore deposits. The classification of igneous rocks is based on the suggestion of Shand. The recognized groups comprise (*a*) the oversaturated rocks, characterized by the possession of quartz, (*b*) the saturated rocks characterized by the possession of alkaline feldspars but no quartz, (*c*) the undersaturated rocks (1) characterized by feldspars and olivine, (2) those characterized by feldspathoids, and (3) those characterized by feldspathoids and olivine. The metamorphic rocks are separated into (1) those affected by igneous exudations and (2) those produced by dynamic metamorphism or a combination of contact and dynamic metamorphism. The exogenetic rocks are divided into (1) weathering residues, (2) detrital sediments, (3) solution deposits, and (4) accumulations of organic matter. Among the solution deposits are placed the oozes, the coral, shelly and similar limestones and bone beds. Otherwise the classification is along the usual lines.

The classification terminates with a table exhibiting the grouping of meteorites according to Prior.

The volume is a very convenient and trustworthy little ready reference handbook.

W. S. Bayley.

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SCIENTIFIC NOTES AND NEWS[1]

GEORGE OTIS SMITH addressed the American Mining Congress on "Some Items in a Prosperity Program" at the meeting in Chicago on October 17.

H. M. EAKIN, of the U. S. Geological Survey, has returned to Washington to complete a geologic report on the Juneau district, southeastern Alaska.

J. B. TYRELL of Toronto is in the Caribou district, northern British Columbia, inspecting some recent gold discoveries.

D. F. HEWETT is engaged in field work for the U. S. Geological Survey near Good Springs, Nevada.

WILLIAM SLOAN, Minister of Mines for the Province of British Columbia, has resumed his work at Victoria after several months' absence on account of ill health.

ALFRED H. BROOKS, head of the division of Alaskan Mineral resources of the U. S. Geological Survey, has returned to Washington after having spent the season in Alaska.

HENRY KRUMB is in Los Angeles, where he expects to remain for some time.

A. D. CHISHOLM has left for South America to examine properties in Brazil for the Steel & Tube Co. of America.

G. F. MOULTON, M. N. BRAMLETTE, AND N. F. BASS are in eastern Montana, mapping parts of the Glendive anticline.

[1] Geologists, mining engineers and others interested in applied geology are invited to keep the editor informed of new investigations of mining districts or scientific studies undertaken by them, together with such other scientific and personal items as may come to their notice.

WILLIAM F. WARD has sailed for Colombia, where he will be engaged in the examination of mining properties for several months.

M. W. HAWARD has been appointed head of the geological and exploration department, which has been recently created by the Compania Minera de Penoles.

L. P. DOVE, assistant State geologist of North Dakota, was engaged during the summer in an investigation of the road materials of the state.

E. T. STANNARD, Vice-President of the Kennecott Copper Corporation, has been in Washington and New York for part of October and November.

JOHN P. BUWALDA, formerly of the Geological Department of Yale University, is now a member of the Geological Department of the University of California.

ROLLIN T. CHAMBERLAIN has returned to Chicago after a summer's investigation of glacial motion in the Alps.

WILLET G. MILLER is again at his office in Toronto.

SYDNEY H. BALL has been made Secretary and Treasurer of the Society of Economic Geologists.

E. DEGOLYER is at present in Europe.

ERNEST HOWE has returned from Litchfield, Connecticut, to New Haven.

F. C. CALKINS, of the U. S. Geological Survey, has returned to Washington after completing his study of the geology and ore deposits of the Cottonwood-Alta district, Utah.

CHESTER W. WASHBURNE has returned to New York from South America, where he spent eight months examining oil properties.

WARREN D. SMITH has obtained leave of absence from the University of Oregon for another year to continue his work in the Philippines under special contract with the Philippine Government.

K. C. HEALD, of the U. S. Geological Survey, started in early November the oil work in the Salt Creek field, Wyoming.

EARL A. TRAGER expects to spend the coming year in Mexico, where he will make a petrographic study of the formations in the Panuco, Ebano and Topila districts.

C. W. PURINGTON sailed on November 18 from Vancouver for Siberia, where he is to be managing director of the Ayan Corporation, Ltd., of London, at Vladivostok.

E. T. DUMBLE is Consulting Geologist and J. A. Taff is Chief Geologist of the newly formed Pacific Oil Company.

ARTHUR R. WEIGALL has arrived in San Francisco from Korea.

F. A. EDSON has resigned from the Oklahoma Geological Survey and has gone to Mexico.

H. KENYON BURCH has recovered completely from a recent illness and returned from Los Angeles to Warren, Arizona, on November 1.

F. B. PLUMMER is at present in Switzerland.

HENRY HINDS is Chief Geologist for the Pantepec Petroleum Company at Tampico.

J. COGGIN BROWN is returning to India shortly, and his place at the department of Commerce and Industry of the Indian Government at Winchester House, London, is now filled by Cyril S. Fox, also of the Indian Geological Survey.

ELIOT BLACKWELDER, previously of the University of Illinois, will teach at Harvard University during the first term next year, taking the place of Professor Daly, who is in South America.

LOUIS A. WRIGHT will arrive in New York from Obermais, Merano, Italy, about December 1.

W. E. WRATHER spent the summer in Alaska.

W. B. EMERY, geologist with the Ohio Oil Company, is working in Utah with headquarters at Caspar, Wyoming.

O. S. FINNIE, of the Mining and Yukon Branch of the Canadian Department of the Interior, has returned to Ottawa after spending the summer in the Fort Norman oil fields.

J. B. OVERSTREET, formerly with the Sun Company, is at present Chief Geologist for the Houston Oil Company, with headquarters in Houston.

S. H. CATHCART, of the U. S. Geological Survey, returned from field work in Montana in early October, and on October 20 was married to Miss Iva Waterbury, of New Haven, Conn.

STEPHEN L. KAFFER, formerly chief engineer of the Burro Mountain Branch of the Phelps Dodge Corporation, at Tyrone, N. M., has accepted a position with the Mine and Smelter Supply Co., at El Paso.

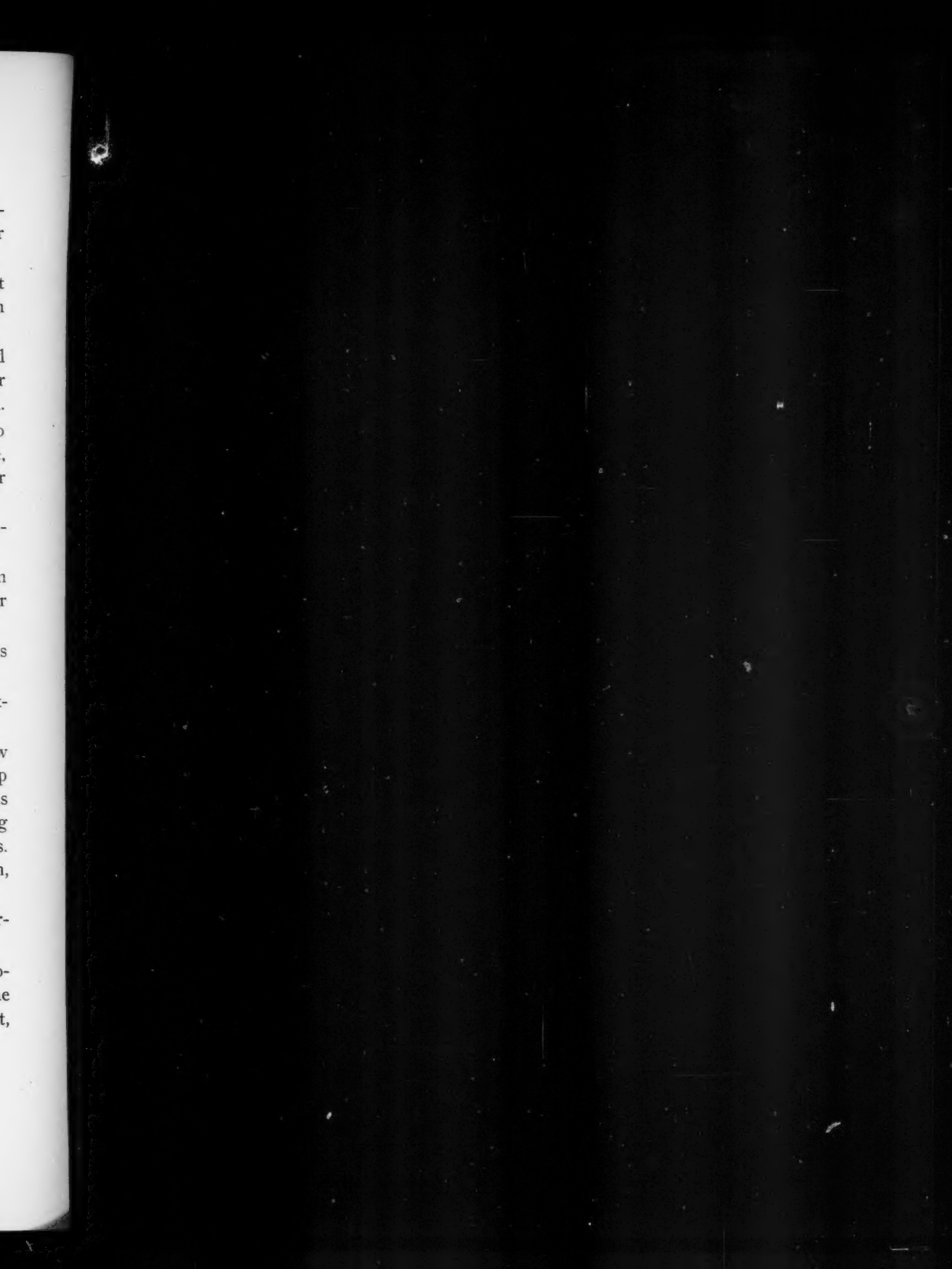
J. V. HOWELL has been appointed Professor of Economic Geology at the University of Iowa.

DONALD F. MCDONALD has returned to New York after an extended trip through southern Mexico for the Mexican Sinclair interests.

ROBERT T. HILL has given up his office at Dallas and has moved to Long Beach, California.

MR. RODERICK CRANDALL is in charge of the Sinclair exploration work in Angola, West Africa.

THE WEST VIRGINIA GEOLOGICAL SURVEY has issued a new edition of the Coal, Oil, Gas, Limestone and Iron Ore map on the scale of 8 miles to the inch. It shows oil and gas pools and structural lines, and is accompanied by a booklet giving the names and addresses of the principal coal mining operators. The price, delivered by mail, is $1. Box 848, Morgantown, West Virginia.

THE SOCIETY OF NEW ENGLAND GEOLOGISTS held an interesting field meet October 12 at Attleboro, Massachusetts.

THE ANNUAL MEETING of the Society of Economic Geologists will be held, in conjunction with the annual meeting of the Geological Society of America, at Amherst College, Amherst, Massachusetts, December 28–30, 1921.